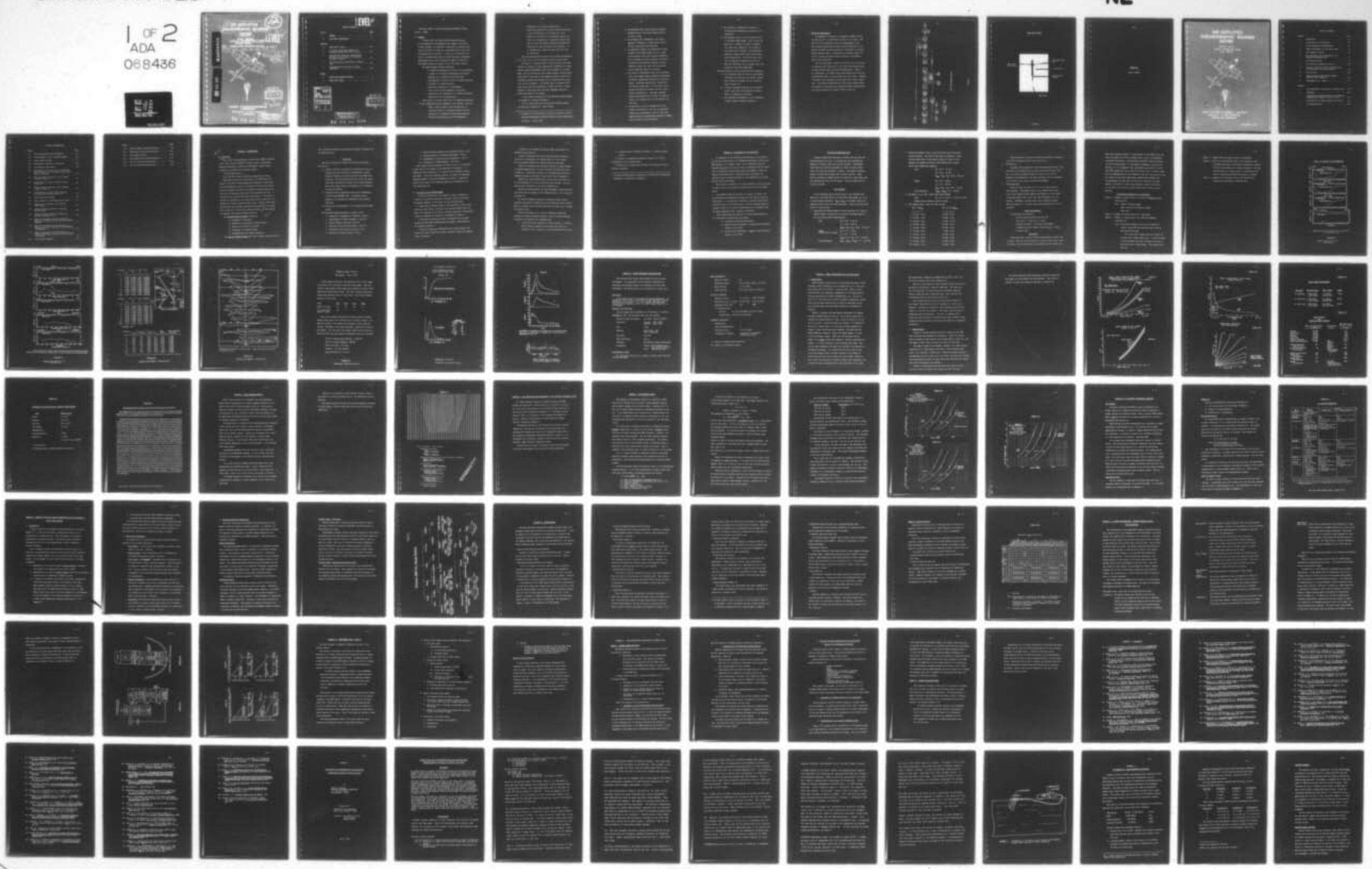
AD-A068 436 NEW HAMPSHIRE UNIV DURHAM MARINE SYSTEMS ENGINEERING LAB F/G 8/10

AIR DEPLOYED OCEANOGRAPHIC MOORING (ADOM).(U)

FEB 79 N00014-78-C-0335

UNCLASSIFIED NL

1 OF 2
ADA
068436



AD A068436

DDC FILE COPY

6

AIR DEPLOYED OCEANOGRAPHIC MOORING (ADOM).

LEVEL

FINAL REPORT

CONTRACT NO. N00014-78-C-0336

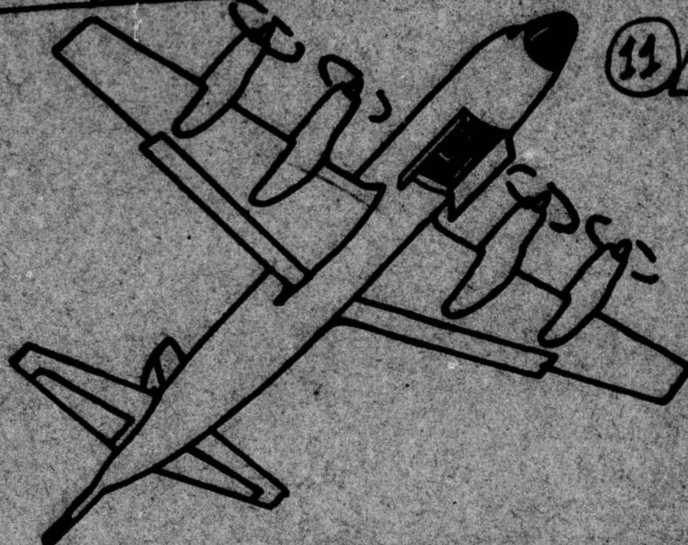
15 FOR PERIOD

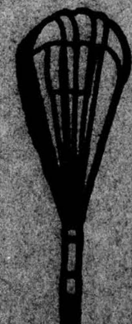
MARCH 1, 1978 - FEBRUARY 28, 1979

9 Final rept. 1 Mar 78 - 28 Feb 79.

11 28 Feb 79

12 144p.





411164

3 MARINE SYSTEMS ENGINEERING LABORATORY

UNIVERSITY OF NEW HAMPSHIRE

LEVEL II

TABLE OF CONTENTS

The Arctic Phase of the Air-Deployed Oceanographic Mooring Project. (ADOM)

1. **Summary:**

In March 1978, the Marine Systems Engineering Group of the University of New Hampshire was engaged by the Office of Naval Research to establish a technique for unmanned drilling of the Arctic Ice cover by an unattended device that could be deployed from an aircraft. It was to be an essential element of a sophisticated system for acquiring deep oceanographic environmental data in the inaccessible regions of the Arctic. This report reviews the results of the first year's efforts.

The tasks assigned included providing:

- a statistical description of the ice to be penetrated
- a review of the several technologies that might be employed for an unmanned air-deployed drill
- the generation of decision rules for system selection
- isolation of a preferred system
- analytical evaluation of its performance
- test of the critical components of the drill
- planning for the construction of a Concept Validation Model (C.V.M.) in the second year

This report of the first year's work is comprised essentially of three independant reports assembled in one binding. They are:

- Phase I Progress Report which includes the ice statistics study, the technology reviews, and the selection of a preferred drilling system approach.
- A report on the modeling of the thermodynamic

performance of the chosen thermal drill.

- A plan for collection of certain key data pertaining to the interactions of a hot water jet on ice. Needed for calibration of the computer model of the drill, this contemplates a cooperative program with the U.S. Army Cold Regions Research and Engineering Laboratory for data collection and evaluation. It is scheduled for completion within the first year of the project.

The three above mentioned reports are included as Appendices A, B, and C, but in fact do comprise the body of this report.

In Figure 1, a Milestone Chart is shown outlining the tasks required to complete a 3-year program that culminates in a demonstrated Advanced Development Model of key elements of an Arctic ADOM. The drill system will have passed through a Concept Validation Phase in this period, and subsystem elements required for deployment erection and drilling will be constructed and tested in an Arctic environment. The program aims at providing sufficient design and field experience to permit the Office of Naval Research to make appropriate decisions regarding exploiting future development of the system.

A more complete description of the proposed on-going program is included in a companion document.[1]

A set of conclusions may be drawn from the three reports included here as Appendices. They include:

---

[1] "A Program for the Second Year of the Arctic Phase of the Air Deployed Oceanographic Mooring" UNH Marine Systems Engineering Laboratory - January 1979.

a. We determined that a drill capable of passing through 50 feet of ice would penetrate 99% of the arctic cover.

b. We determined that, depending on the system employed, a design for a lesser depth, even to 35 feet, could prove cost effective.

c. We examined 87 systems, and variations of those systems, for drilling through the ice. Based on the decision rules that stressed reliability, and a liklihood for early reduction to practice, a system was selected that employed a battery-powered hot water jet, that used recirculated and re-heated melt water for drilling.

d. We created a thermodynamic model of the proposed drill, and through computer modeling, established the guiding engineering parameters for the drill design. Resulting questions were raised about the thermal coefficients of the ice that will be actually encountered in Arctic ice with a high velocity scrubbing jet. The model confirmed earlier anticipation that 35 K.W.H. of energy is likely to be required for a 6 inch diameter, 50 foot hole.

e. We generated a plan for verifying the actual thermal coefficients of ice, thru an experiment conducted in cooperation of the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). This experiment is now in progress.

f. We initiated an examination of methods of determining the geographical position of the emplantment.

g. We generated a first fix on the physical form of the ARCTIC ADOM package. First sizing indicated that a cylinder 21 inches in diameter, 132 inches long, weighing in the vicinity of 1450 pounds may be required. The experiences ahead may, indeed, modify these target dimensions substantially. The initial size projection is apparently compatible with the P-3 bomb bay limitations, and is markedly less than necessarily more bulky OCEAN ADOM.

From these studies, we have reached several judgements:

A. The technology exists to build an air-droppable unattended ice drill that can provide a modest hole 6 inches in diameter (15 cm) through 50 feet of Arctic ice.

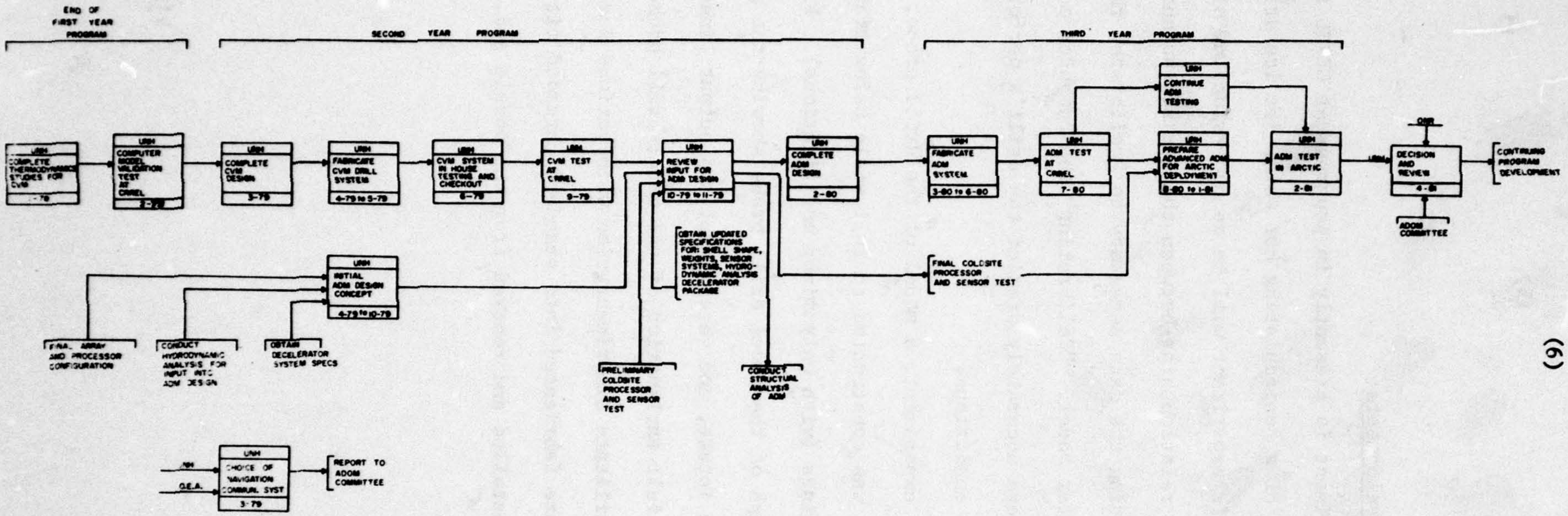
B. A Concept Validation Model may be constructed within a year that can demonstrate the feasibility of unmanned ice drilling.

C. The problems of deployment, not yet considered in depth promise reasonable solutions.

2. Additional Developments

An experiment is presently in progress at CRREL to verify the operation of a recirculating hot water jet ice drill. The results of this experiment will be an understanding of the heat transfer relationships between the jet stream and the ice, thereby providing the data necessary to "calibrate" the thermodynamic computer model. "Calibrating" the computer model will allow us to more accurately predict the drill's performance under varying conditions.

For this experiment, a model of the drill probe, as presently conceived, was constructed to full scale using standard plastic pipe fittings (with only minor modifications). Figure 2 is a photograph of the model drill probe showing the nozzle end, recirculating intake, and water input and output lines. Appendix C contains a full explanation of the model drill probe's operation. To facilitate experimentation with various nozzle sizes, the nozzles are fabricated into standard threaded fittings which are easily installed and removed from the nozzle end.



ARCTIC ADOM PROGRAM OVERVIEW

FIGURE 1

MODEL DRILL PROBE

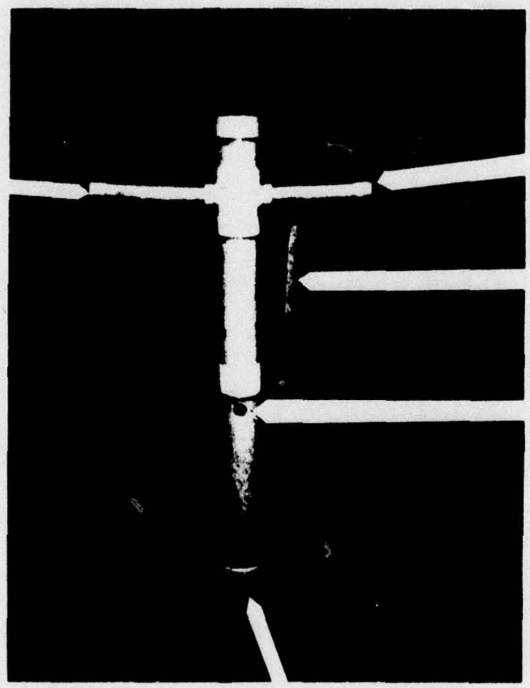


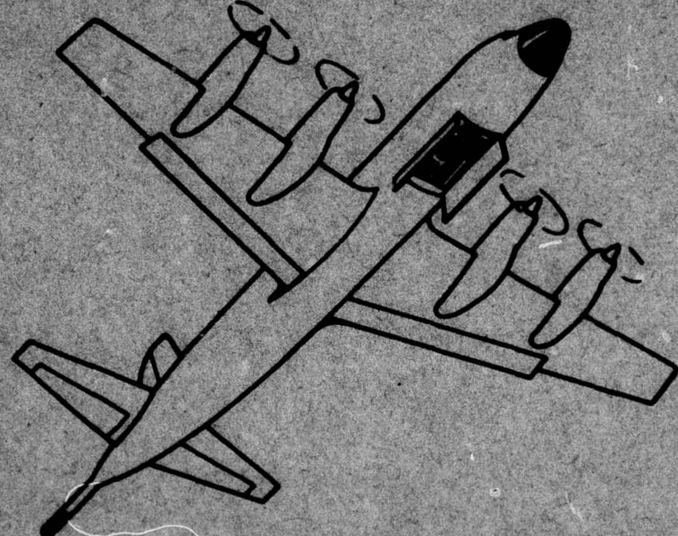
FIGURE 2

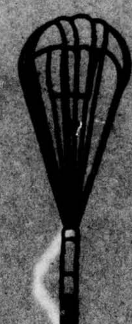
APPENDIX A

PHASE I REPORT

AIR DEPLOYED OCEANOGRAPHIC MOORING (ADOM)

ARCTIC ADOM
CONCEPT DEFINITION PHASE
FINAL REPORT





MARINE SYSTEMS ENGINEERING LABORATORY
UNIVERSITY OF NEW HAMPSHIRE
DURHAM, NEW HAMPSHIRE

SEPTEMBER 1, 1978

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure		Page

ABSTRACT

SECTION 1: INTRODUCTION

A. Objectives

The Air Deployed Oceanographic Mooring Study (ADOM), sponsored by the Office of Naval Research, through a team of contractors, explores technology for deploying oceanographic sensors from an aircraft in two regions of the world's oceans:

in the open ocean; and

in the Polar oceans, involving substantial ice cover.

This report covers the initial phase of an ADOM Study, performed by the Marine Systems Engineering Laboratory of the University of New Hampshire, which is responsible for the concept definition and feasibility evaluation of systems for penetrating the ice cover and for deploying sensors and a data communication link. In the first year, a Concept Definition Phase (March - July 1978) involving the development of ice penetration system concepts is to be followed by a Concept Validation Phase (July - February 1979) which involves test of key system components and preparation for a second year in which full scale Arctic tests are planned. The UNH program is conducted under Contract N00014-78-C-0335.

ABSTRACT

The Concept Definition Phase consists of:

1) Assessment of Technology
2) Examination of Alternative System Concepts
3) Analysis and Trade-off of Systems
4) Development of a Design Concept
5) Recommendations for Concept Evaluation

The Concept Validation Phase will seek to design, develop and pro-

vide preliminary testing of ice penetration systems consistent with the ADOM objectives.

Priorities

The major priorities for project activities during Phase I have been to:

1) Analyze a variety of concepts for penetration of the ice-covered ocean with the goal of recommending, on sound technical grounds, one system that best meets ADOM specifications. The over-riding constraint is that the chosen system have the highest potential for successful development; hence state-of-the-art technology is to be employed as often as possible.

2) Contribute Arctic engineering concepts and technologies to the overall ONR-ADOM team. A principal initial emphasis is on defining the environment that the drill must face.

3) To plan for the development of an operational Arctic/ADOM system.

The principal program milestones for Phase I were:

1. Completion of assessment of technology - April 1
2. Establishment of system boundaries - April 25
3. Initial trade-off analysis - April 25
4. Selection of two preferred systems - April 25
5. Alternative system design and layout - May 1
6. Selection of preferred system - May 15

7. Preferred system analysis and preliminary design - June 1

8. Program planning for prototype development - June 10

9. Recommendation and plans report preparation - June 25

10. Presentation to ADOM Committee - July 11-12

The original task descriptions for Phase I and II, as established at the start of the program, are included here as Appendix I. On reading the task description, it is seen that four candidate systems were named. As the study evolved, however, the number of candidates expanded markedly to over 80 combinations of systems. Despite the growth of the scope of this program, however, the milestones still were effectively met.

B. <u>The Phase I Arctic ADOM Program</u>

To meet the objectives of the program as shown in Appendix I, a series of interrelated tasks were undertaken, which are reported as separate chapters in this report, and are outlined below.

A major area of unknown relates to the specifics of the ice that covers the Arctic Ocean: how deep it is, how much extends above the water, how convolved is the surface, and what slopes may be encountered. A study of available ice statistics is described in Section 2.

A drill must be developed, which is compatible with the ADOM system, and thus target specifications are needed. Specifications are offered in Section 3.

A series of bench mark technologies exist which influence the choice of an Arctic ADOM drill system. Reports on these are included below, as follows:

In Section 4, we examine the thermal energy requirements for melting a hole in sea ice.

Section 5 introduces the subject of Heat Transfer Analysis, a task that is continuing in the ongoing Phase 2 of this program. Here the optimum mechanism for thermal drilling is explored.

Section 6 introduces the experiences reported by James Browning of Browning Engineering Co. in their Antarctic drilling work using a flame-jet. Conclusions, offered by Mr. Browning, that pertain to unmanned drilling are included in the Section 6 and in Appendix 3.

Sandia Corp., Naval Ordnance Lab, and the Coast Guard have led in the development of ice and terrestrial impact systems. Section 7 applies their conclusions to the Arctic ADOM problem.

Mechanical drilling offers the major advantage of high efficiency, but entails serious problems for an unmanned system. It is discussed in Section 8.

The several candidate systems and alternative power sources eventually generated a decision-tree with 87 potential system options. Section 9 presents these, and the logic which was used to sort through this unwieldy list.

Derived from Section 9 is a list of candidate systems that survived the initial rejection criteria. These are further winnowed in Section 10 to generate two recommendations.

a. A system with high probability of early success -- a battery-powered hotpoint employing recirculated melt water as a "scrubber", with a variant of a battery-powered hot water jet.

b. A system worthy of research attention -- a Super-corroding Alloy.*

In Section 11, engineering attention is given to an initial visualization of the proposed drill.

In Section 12, a program plan for Phase II and eventual system testing is reviewed.

---

* The Super-Corroding Alloy, developed by the Naval Civil Engineering Laboratory, is described in Appendix 4.

SECTION 2: AN ANALYSIS OF ICE STATISTICS

An assessment of the probability distribution of ice-thickness for the ice-covered ocean is of fundamental importance to the Arctic/ADOM program. As we design a drill, it is essential to know the probable thickness of the ice that will be encountered and the likelihood of encountering substantially greater thicknesses. Since the energy for drilling must be transported within the system, ice statistics have a profound influence on the probability for success, and the cost of the mission.

This report is a summary of all data available to us and provides the basis for the ice thickness specifications for the Arctic/ADOM system.

Ice thickness data for the Arctic is sparce, and indeed, the various methods of obtaining thickness have been subject to serious deficiencies. It is difficult, therefore, to develop statistically sound data bases for the whole Arctic. The data contained herein is intended, however, to provide the ADOM team with a reasonable basis for making judgements about expected ice thickness.

Three methods have been employed to develop understandings of ice thicknesses, distributions, and texture.

1) Ice Borings & Physical Measurements
2) Submarine Sonar Measurements (Measure bottom profiles relative to sea level)
3) Aircraft Laser Measurements (Measure surface profiles relative to sea level)

Profiles and Thickness Data

Several attempts have been made to profile both the upper and bottom surfaces of the sea. Ice borings are time consuming and expensive to obtain, hence very few are available. Simultaneous laser surface and bottom measurements by laser and sonar, while tried, are virtually impossible to obtain. The figures following, however, provide some insights into the basic profiles. These data are provided as examples which are typical of a much larger data set numbering well over 10^6 data points. From the larger data set we have concluded:

Ice Thickness

In the following, $\bar{X}_k$ *is the mean value of the indicated keel depth,* $\bar{X}_s$ is the mean value of the indicated ridge height, σ_k, σ_s is a stated standard deviation. $\bar{X}_{kmax}$, $\bar{X}_{smax}$ are maximum, 99% of all observed values of keel and ridge dimensions. These are derived from the $\bar{X} + 3\sigma$ value quoted.

1. Using 1000 mile AIDJEX submarine profile data and a 1:8 ratio of surface ridge to bottom keel, we found the following (based on over one million profile measurements).

Keel:	$\bar{X}_k = 14.0'$ (4.27 m)
	$\sigma_k = 8.6'$ (2.62 m)
	$\bar{X}_{kmax} = \bar{X}_k + 3\sigma_k = 39.8'$ (12.1 m)
Ridge: (*inferred by 8:1 ratio*)	$\bar{X}_s = 1.8'$ (.55 m)
	$\sigma_s = 1.1'$ (.34 m)
	$\bar{X}_{smax} = \bar{X}_s + 3\sigma_k = 5.1'$ (1.55 m)
Total Thickness:	$\bar{X}_{max} = \bar{X}_{kmax} + \bar{X}_{smax} = 45'$ (13.7 m)

2. Using Peter Wadham's data, it was found that .54% of the keels exceed 30 meters. (He found 45 such keels in 4000 km of track.) He found mean drafts in the range of about 23.7 feet (7.2 m). Assuming the standard deviation (using AIDJEX data) is about 60% of mean, Wadham data suggests:

Keel: $\bar{X}_k = 23.7'$ (7.2 m)

$\sigma_k = 14.2'$ (4.3 m)

$\bar{X}_{kmax} = \bar{X}_k + 3\sigma_k = 66.3'$ (20.2 m)

Ridge: $\bar{X}_s = 2.9'$ (.88 m)

$\sigma_s = 1.8'$ (.55 m)

$\bar{X}_{smax} = \bar{X}_s + 3\sigma_s = 8.3'$ (2.5 m)

Total Thickness: $\bar{X}_{smax} + \bar{X}_{kmax} = 75'$ (22.8 m)

3. Williams, et. al. Data (Trans Polar Drift Stream)

Keel: $\bar{X}_k = 11.8'$ to $16.7'$ (3.6 m to 5.1 m)

Ridges can be inferred by the 8:1 ratio.

4. Ten Submarine Runs (each over 100's of km)

Est. of $\bar{X}_{kmax}$	Est. of σ_k @ $\bar{X}_{kmax}$
1 - 29 feet (9 m)	13 feet (4 m)
2 - 23 feet (7 m)	13 feet (4 m)
3 - 10 feet (3 m)	5 feet (1.5 m)
4 - 26 feet (8 m)	16 feet (5 m)
5 - 26 feet (8 m)	16 feet (5 m)
6 - 13 feet (4 m)	7 feet (2 m)
7 - 29 feet (9 m)	16 feet (5 m)
8 - 29 feet (9 m)	20 feet (6 m)
9 - 20 feet (6 m)	13 feet (4 m)
10 - 26 feet (8 m)	13 feet (4 m)

Using these data, we obtain an estimate of maximum ice thickness of the 99.7% confidence level of 62.7 feet (19 m).

5. LeSchack Data

He suggests 90% probability of ice thickness being 26 feet (8 m), from which one can deduce that the mean of his data is about 13-14 feet (4 m) and his standard deviation is about 8 feet (2.5 m). Therefore, ice thickness for the 99.7% confidence level is estimated to be 36 feet (11 m), given a Gaussian distribution.

6. Swithinbank Data

Mean keel draft was found to be 2.7 to 6.6 meters based on 10 km averages. Swithinbank states "In the central Arctic basin over a track length of about 1000 km they (Hibler, et. al.) found a mean keel draft of 9.6 + 0.6 m and a mean frequency of 4.3 + 1 keel/km. Remarkably, our data yields almost identical results: mean keel draft 9.6 + 1.0 meter, and a mean frequency of 4.2 + 0.6 keels/km."

Other Ice Parameters

The published data suggests:

- Surface texture maximum slope 20° ± 10°
- Snow cover -- likely cover = 3 feet
- Seasonal variation = less than 1 meter total
- Latitude variation = about 1 meter on mean , or about 3 meters total

Conclusion

These data cover a range of spacial distributions, seasons, and textures. They were made available as a series of data points, each an average of many measurements and are quoted by most sources as a

mean and a standard deviation. An assumption is thus implied that the data is Gaussian, but there is evidence that, in fact, it approaches a Rayleigh distribution. The statistics, therefore, must be corrected for this obvious skewing. If one applies a judgmental correction for skewing, it is our suggestion that the maximum encountered ice thickness (99% probability) lies in the 50 to 55 feet (15 to 17 meter) range. We are recommending that an ice thickness of 50 feet (15 meters) be used as a basis for the Arctic ADOM design, implying that perhaps 1% of the deployments will fail due to thicker ice. Attention is drawn, however, to Section 11, which argues plausibly, based on this data, for an actual 35 feet (10.7 m) system design limit, based on a cost analysis.

<u>Illustrations relating to Ice Statistics</u>

Figure 1 -- Example of western Arctic ice taken from <u>Ackley, et. al</u>. Reference #10.

Note: Angles of Surface Ridges
Depth of keels and heights of ridges
Snow cover

Figure 2 -- Example of western Arctic ice - same source

Figure 3 -- Example of eastern Arctic ice, taken from Wadhams, Reference #70.

Note: The high percentage of ice that was observed to exceed 5 meters and the relatively small value of mean elevations noted.

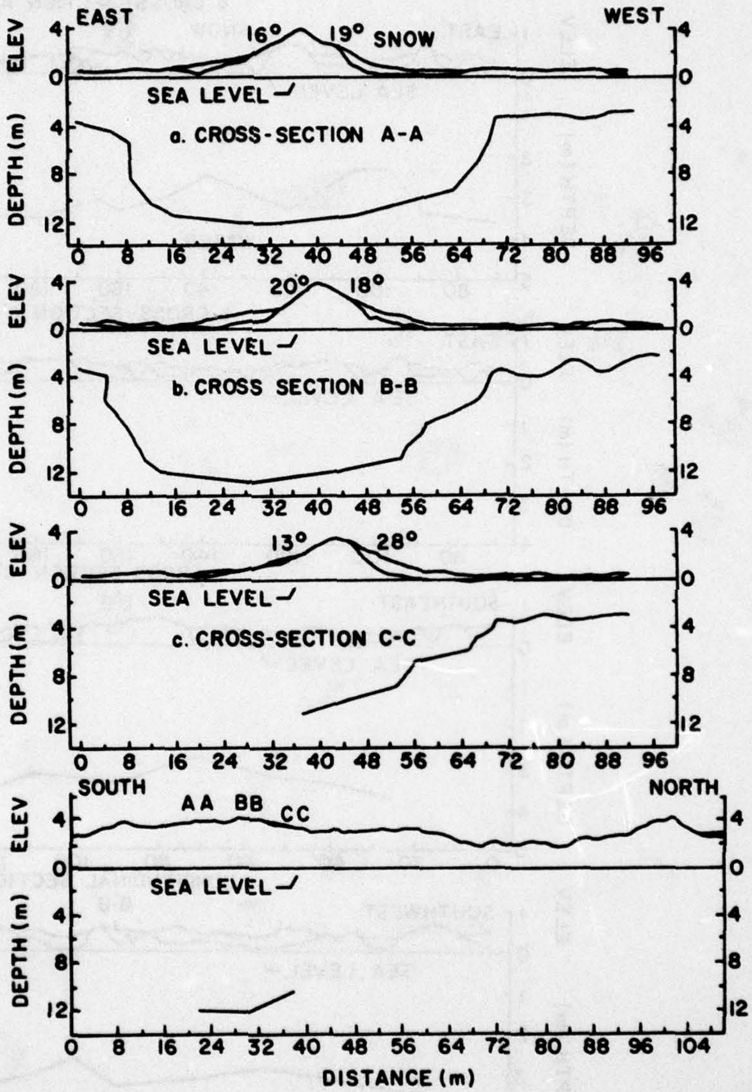
The second table supplies mean keel depths (h) and mean sail (ridge) heights (h_s). A table is added to the referenced data that calculates the ratio of mean keel depth to ridge height. The average ratio was 9.21

Figure 4 -- Example Data from Eastern Arctic, from Wadhams.

Figure 5 -- This is an internal UNH report on the analysis of over 1,000,000 unpublished ice thickness measurements, supplied by AIDJEX and presented on a computer printout. The range and distribution of extreme points is indicated and the basis of discarding erroneous data points is reviewed.

Figure 6 -- Example of ice thickness data in the Eastern Arctic published by Swithinbank in Reference #74.

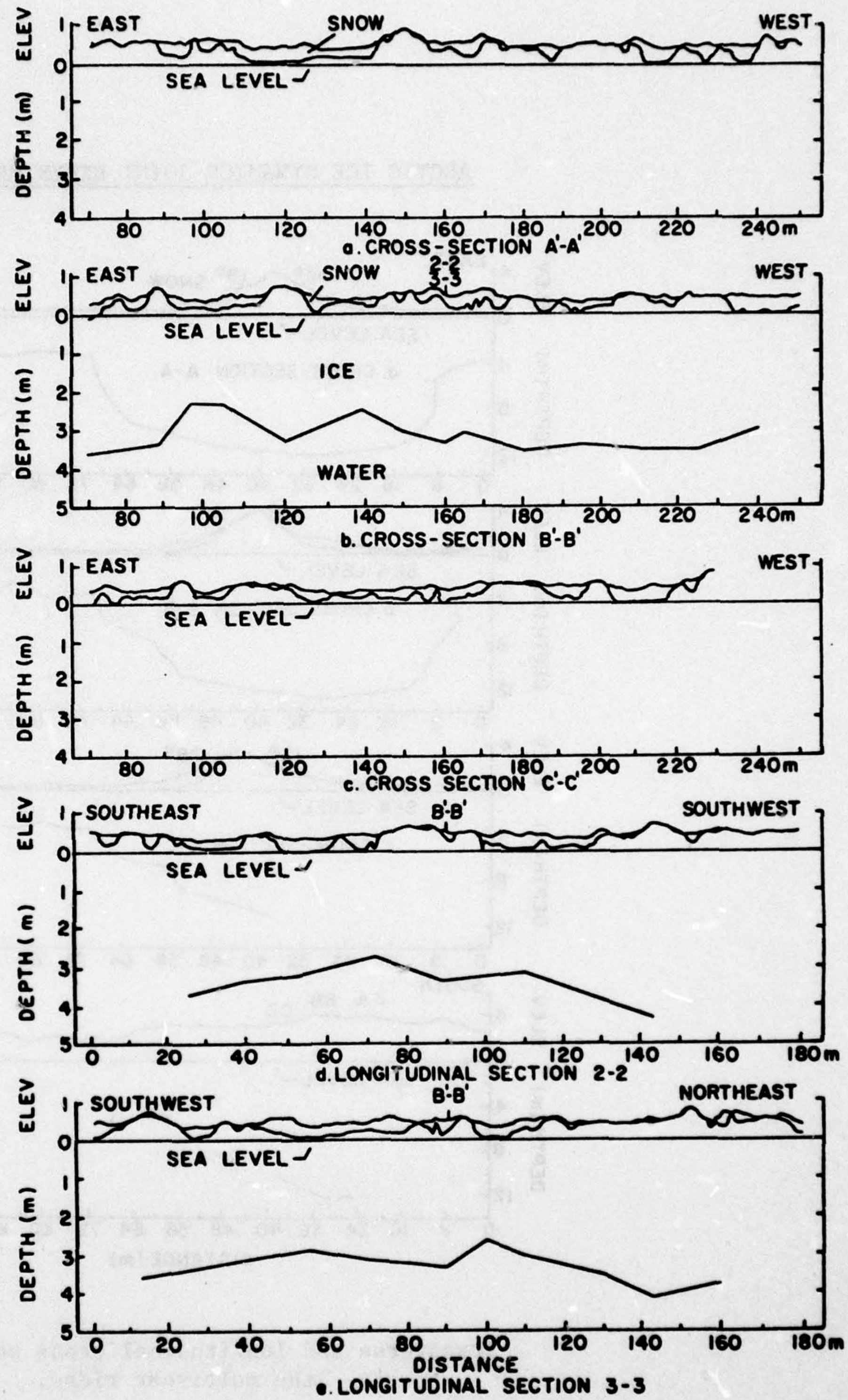
ARCTIC ICE DYNAMICS JOINT EXPERIMENT



Transverse and longitudinal cross sections of the multiyear ridge.

Figure 2-1

Adapted from Ackley, et al
Reference #10

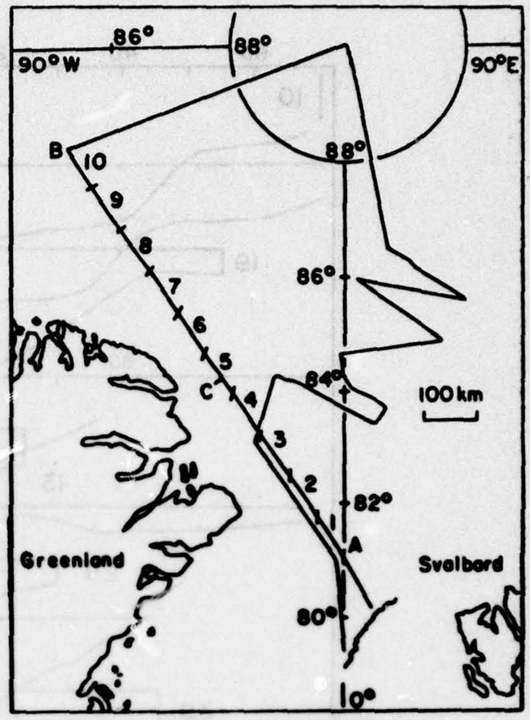


Cross sections of the 5 profiles studied, illustrating snow and ice elevations and random thicknesses. The vertical scale is exaggerated by a factor of 10 compared to the horizontal scale.

Figure 2-2

Adapted from Ackley, et al
Reference #10

Section	Keels (h_o = 9 m) μ_k	$\overline{h}$	A	a
1	2.996	12.986	1.160	0.007876
2	3.312	13.884	0.872	0.005885
3	3.704	14.203	0.871	0.005364
4	3.209	13.591	0.946	0.006437
5	3.648	14.141	0.876	0.005459
6	4.369	14.631	0.898	0.004771
7	4.111	14.009	1.034	0.005672
8	3.937	14.347	0.883	0.005152
9	3.830	13.939	0.988	0.005790
10	4.304	15.521	0.696	0.003824
Total	3.742	14.188	0.885	0.005387



TRACK OF HMS SOVEREIGN

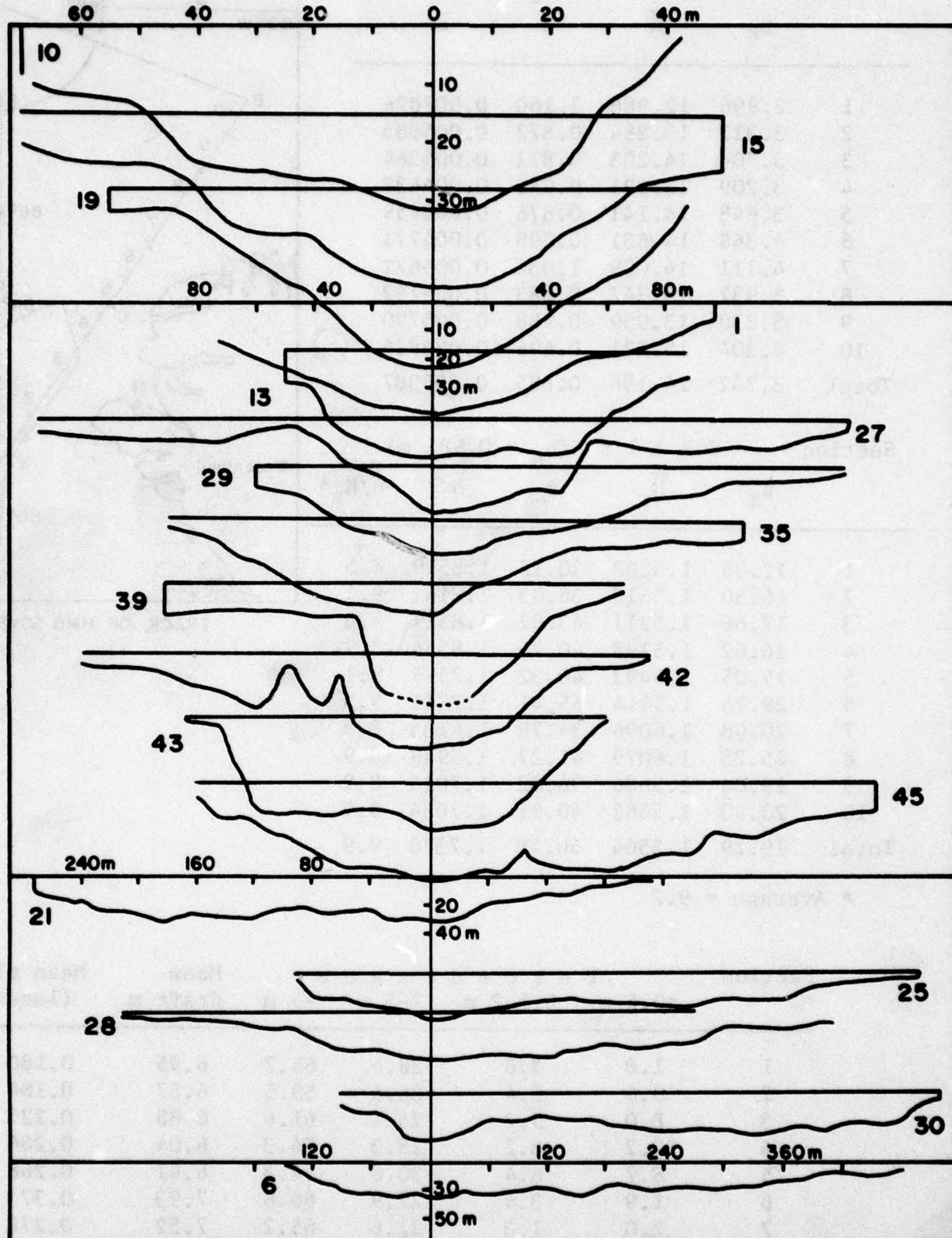
Section	Sails (h_s = 0.981 m) μ_s	$\overline{h}_s$	B	b	h/h_s*
1	12.36	1.5208	30.15	1.8519	8.5
2	16.50	1.5319	38.03	1.8147	9.1
3	17.66	1.5211	43.02	1.8511	9.3
4	16.62	1.5198	40.76	1.8554	8.9
5	19.05	1.5492	40.32	1.7595	9.1
6	29.75	1.5414	65.41	1.7841	9.5
7	20.68	1.6006	34.78	1.6135	8.8
8	25.28	1.6079	41.27	1.5949	8.9
9	19.04	1.5686	36.82	1.7015	8.9
10	20.93	1.5662	40.91	1.7084	9.9
Total	19.79	1.5564	40.48	1.7376	9.9

* Average = 9.2

Section	Percentages <0.5 m	0.5-2 m	2-5 m	>5 m	Mean draft m	Mean elevation (laser) m
1	1.8	3.8	28.6	65.7	6.95	0.180
2	8.6	5.4	26.6	59.5	6.87	0.184
3	8.0	5.2	25.1	61.6	6.88	0.223
4	12.2	8.2	25.3	54.3	6.04	0.206
5	8.7	6.4	30.6	54.3	6.41	0.266
6	1.9	3.4	27.9	66.8	7.93	0.373
7	2.0	1.3	31.6	65.2	7.52	0.278
8	1.1	2.7	31.3	64.9	7.51	0.317
9	2.1	1.9	33.7	62.3	7.20	0.283
10	1.3	0.6	21.4	76.5	8.92	0.236

Figure 2-3

Adapted from Wadhams - Reference #70



Representative profiles of deep keels. Range is measured from point of greatest draft.

Figure 2-4

Adapted from Wadhams - Reference #72

AIDJEX Ice Data - 4/27/78

Data Report - June 7, 1978

On the computer print-out, areas peaking in the 70 foot range, in the 80's, 90's, and those in the 100's were logged. The total number of data points in each range and the number of areas in which these were found are given below. (An "area" includes consecutive peaks within 120 data points of each other.) The absolute maximum observed is 102.1 feet.

Range	70's	80's	90's	100's
Total # in range	311	73	36	6
# of areas which peaked in range	18	7	5	1

Most of the numbers increased and decreased fairly regularly. However, there were a few irregularities of possible interest. By some error, many of the numbers had 200 added to them; these are circled. The number -10.0 showed repeatedly, especially in areas of low numbers. In a few areas, the numbers jumped from low values to 80's and 90's; since these appear unreasonable, they were discarded.

Total # of good points processed: 1,076,580

Total # of points rejected: 300,600

Mean of the data: 14.0 feet

Variance: 74.0 feet squared

Standard Deviation: 8.6 feet

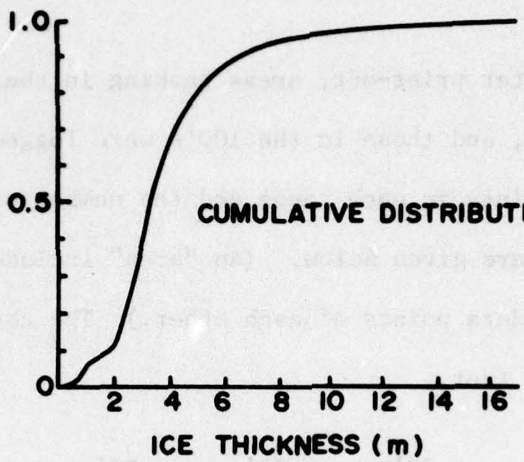
Figure 2-5

Preliminary unpublished results

ICE THICKNESS DISTRIBUTION

AIDJEX SUBMARINE PROFILES
400 KM LINE AT 73°N, 137°W

SPRING 1976



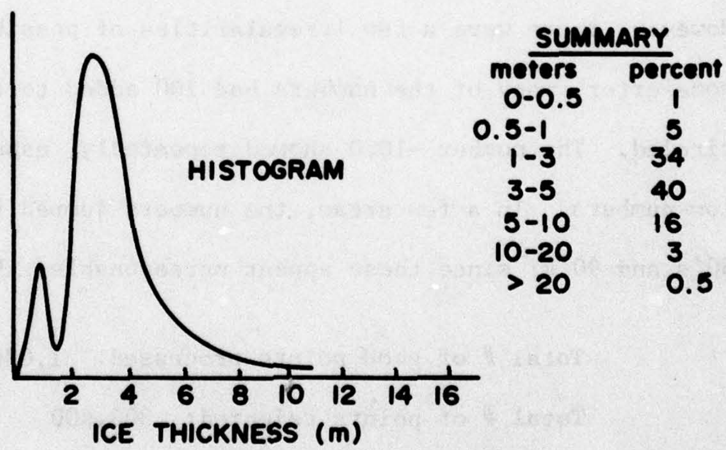
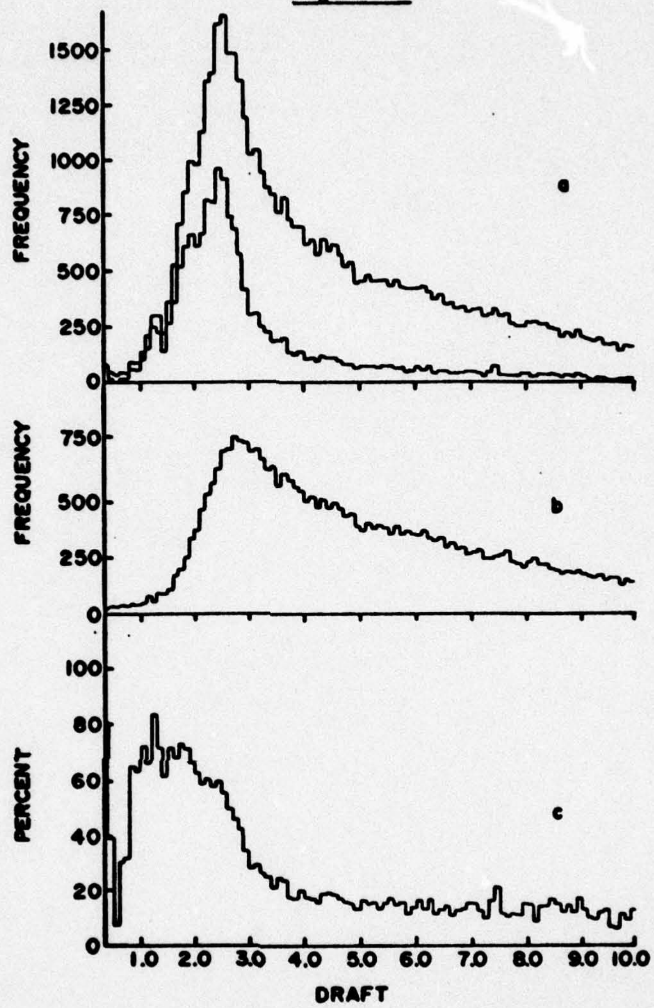


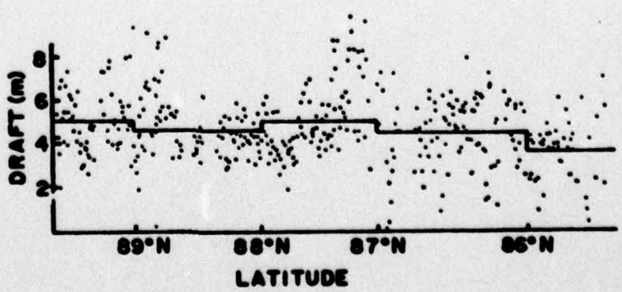
Figure 2-5 (Continued)

Preliminary unpublished results

Figure 2-6



HISTOGRAMS OF ICE DRAFT IN LAT. 89-90°N. (a) ALL ICE (UPPER CURVE) AND LEVEL ICE (LOWER CURVE). (b) RIDGED ICE (c) LEVEL ICE AS A PERCENTAGE OF ÅLL ICE.



MEAN ICE DRAFT FOR 1 km SECTIONS AND FOR EACH DEGREE OF LATITUDE.

SECTION 3: SYSTEM ENGINEERING SPECIFICATIONS

This section offers target specifications for the prototype development. It is generated for the purposes of bounding the deployment and drilling systems, but interfaces with other ADOM sub-systems. The specifications are not definitive in these areas.

DEPLOYMENT

On ice delivery will be the normal operational deployment. The system will also be able to withstand open lead deployment (initial deployment in open water); i.e., it is buoyant, and withstands stresses during freezing, but will not stand closing forces due to ice movement.

PHYSICAL SIZE AND WEIGHT

Size and weight will be suitable for P-3 Aircraft, if possible.

ENVIRONMENT (*Ref:* MIL STD 810B, 210B, 167, MIL a-8591E)

Altitude (flight and launch)	Sea level - 9144 m (30,000')
Temperature	Storage: -62°C, +82°C Working: -40°C, +55°C
Wind	40 KN
Humidity	Electronics: 85% Case: Immersion
Salt Water	Salt Fog
Peak Acceleration	100 G
Vibration	MIL STD 810 B Class B (Aircraft)
Reliability	System: 90% reliability for 1 year mission duration Drill: 95% success ratio

ENVIRONMENTAL IMPACT

No long-lasting effects due to chemical residues result from the drilling procedure.

SENSOR SUBSYSTEM *

Number of Sensors	40
Measurement Depth	100 to 1000 m (328.1' to 656.2')
Depth Accuracy	± 1 m (3.28')
Sensor Spacing	20 to 200 m (65.6' to 656.2')

ICE DRILL SUBSYSTEM

Maximum Ice Depth		15 m (49.2')	($4\sigma \cong$ 100.00%)
Hole Size in Ice	5 cm (2")	10 cm (3.9")	15 cm (5.9")**
Confidence Level	90%	95%	99%**

Ice Characteristics

Physical: as found throughout the Arctic Ocean

Surface Slope: 20° from the horizontal

ELECTRONIC SUBSYSTEM *

Sampling Rate	*
Data Transmission Rate	*
Operational Life	6 to 12 months
Orientation of Antenna	compatible with satellite acquisition of data

* subject to further system definition

** subject to cost benefit studies

SECTION 4: ENERGY REQUIREMENTS FOR THE ARCTIC-ADOM

A. Energy Needs

Three excellent studies exist for determining the amount of heat required to drill, thermally, a hole through Arctic ice: Tien, Ref. # 64, Morev, Ref. # 46, and Mr. L. Bonde of EGG. They all derive from different, but compatible, assumptions on ice characteristics, drilling efficiencies, physical configurations, etc. The work of Tien is in a form that may be directly related to engineering calculations, and has been employed here to study the trade-offs of hole size, drilling speed and power/energy required to accomplish the drilling.

Figure 4-1 examines the power/energy requirements for thermal drilling through 8 meters of sea ice. Here a 200 cm long drill is assumed with enough diversion of heat to keep the drill free of the ice on its sides. Convection heating was assumed. The diameter of the drill is varied from 3 to 42 cm, while drilling speeds of 30 minutes, 3 hours and 5½ hours were examined. The power (KW) and energy (KWH) were computed. Figure 4-2 expands Figure 4-1 in the 6 to 16 cm diameter region. (Note that the horizontal axis in Figure 4-2 is radius rather than diameter.) Several conclusions are evident. It is more efficient to drill rapidly than slowly. The rate of power expenditure obviously rises rapidly as the duration of drilling is shortened. It is noted that for holes in the 6 inch (15.25 cm) diameter region the power required to go 8 meters in typical sea ice is not out-of-reach, less than 25 KWH. Figure 4-1 also records the experience of several reported field operations, two of which lie quite reasonably within the predictions of this model.

The calculations of Bonde in the ADOM report of April, 1978, also are quite consistent with those presented here.

Figure 4-3 illustrates the cost in energy to drill a given hole at various drilling rates, using the TIEN model. The basic text "Ice Core Drilling", the 1974 University of Nebraska reference, offers an empirical chart displaying power, speed, and hole size relationships which we have shown as Figure 4-4.

Note is made that the study of ice statistics, Chapter 2 of this report, indicates that a 3σ ice thickness of 50 feet must be expected. In Figure 4-5, therefore, these calculations are extrapolated to a 50 foot ice thickness. This table forms the basis for subsequent system calculations. It states, in summary, that a 6 inch hole may be drilled in 53 minutes with about 35 KWH of power. Assumptions have been made on efficiency that make this a reasonable expectation.

B. Energy Sources

A study of the many potential sources of energy for the ADOM drill discloses some remarkable relationships. Figure 4-6 reviews some 15 available energy sources, their energy density, their cost, and the weight of power source to drill a 50 foot, six inch hole.

The range of values are astounding. Weights, for a given energy, range from 5.5 to 2500 pounds, a 450 ratio. Cost of energy ranges from $ .50 to $16,930, a 34,000 ratio. While some sources require an accompanying facility to make use of the energy, the table does indicate the extraordinary diversity in power sources and underlines the remarkable role of petroleum in our economy.

Figure 4-7 lists some of the facilities that might be used to generate energy and compares their weight per watt delivered.

The field experience with many drills, primarily mechanical, was summed up in the volume "Ice Core Drilling". Their data is repeated, in the form originally presented, in Figure 4-8.

Figure 4-1

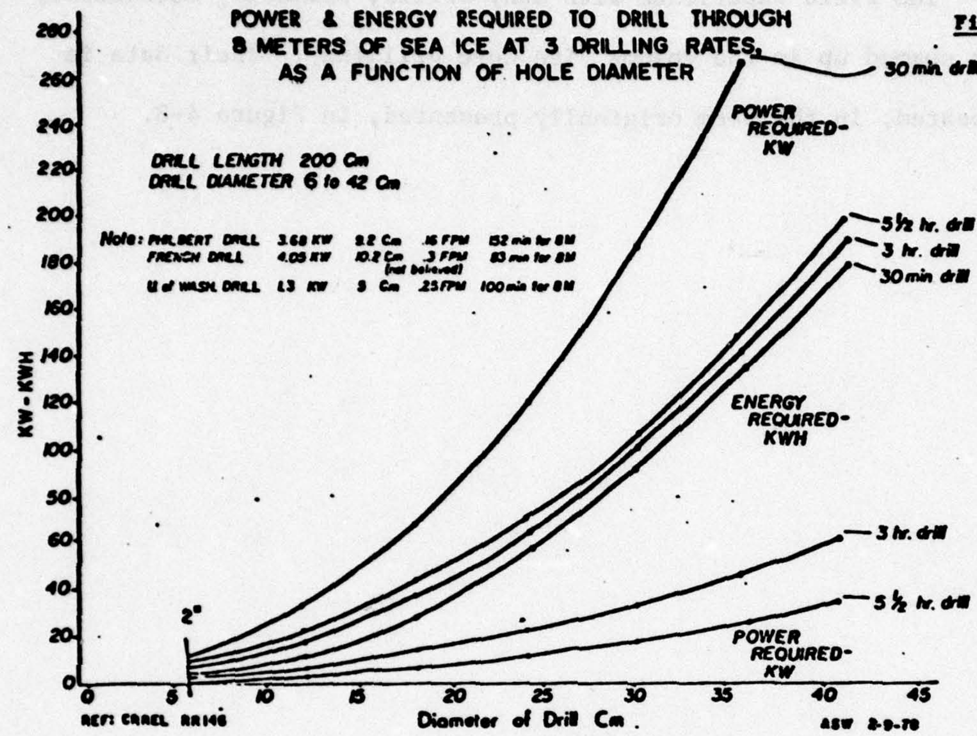


Figure 4-2

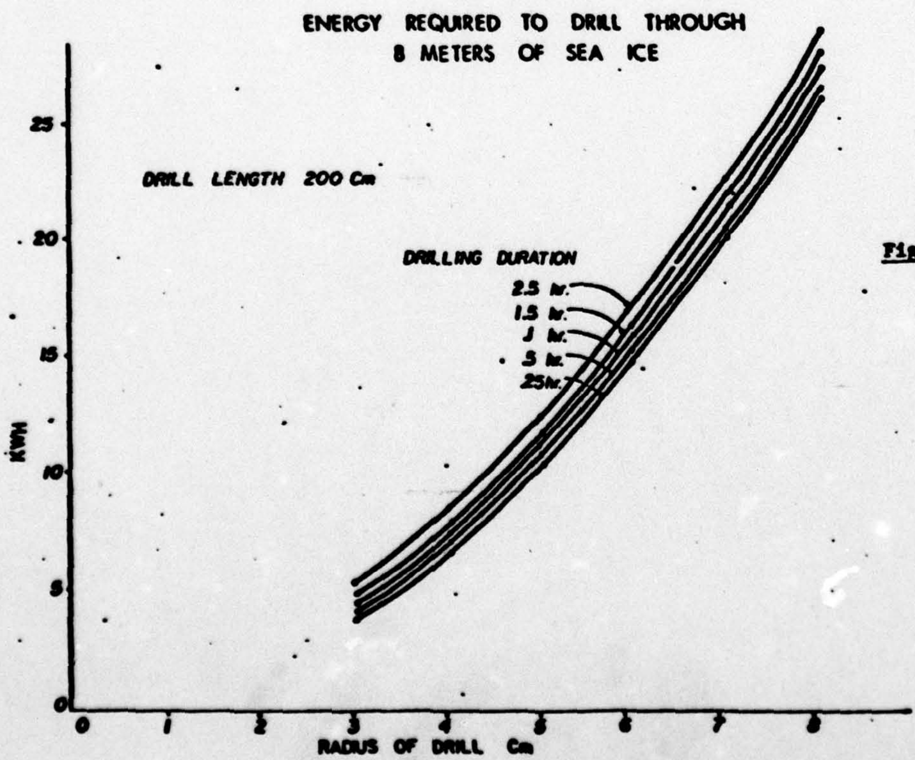
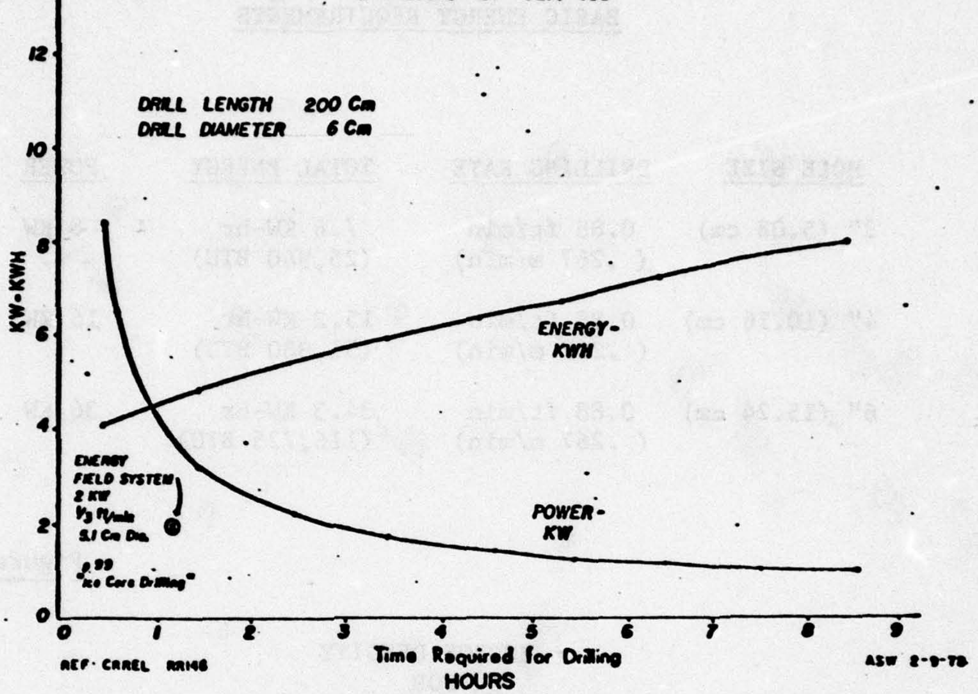


Figure 4-3

POWER & ENERGY REQUIRED TO DRILL THROUGH
8 METERS OF SEA ICE



DRILLING RATE vs. POWER INPUT
FOR VARIOUS HOLE SIZES

Figure 4-4

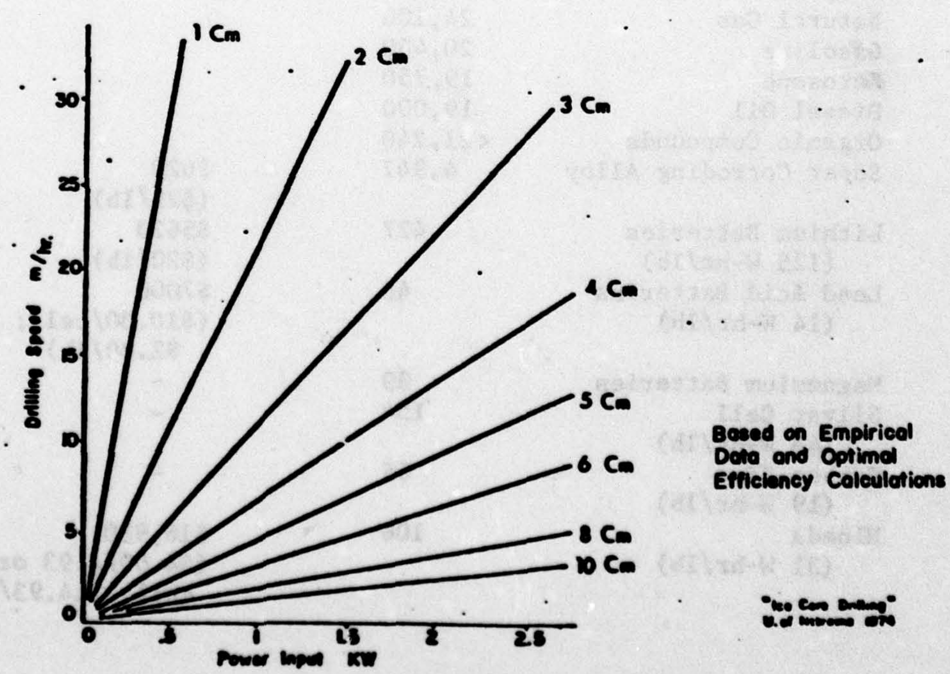


Figure 4-5

BASIC ENERGY REQUIREMENTS

HOLE SIZE	DRILLING RATE	TOTAL ENERGY	POWER
2" (5.08 cm)	0.88 ft/min (.267 m/min)	7.6 KW-hr (25,940 BTU)	8 KW
4" (10.16 cm)	0.88 ft/min (.267 m/min)	15.2 KW-hr (51,880 BTU)	16 KW
6" (15.24 cm)	0.88 ft/min (.267 m/min)	34.3 KW-hr (116,725 BTU)	36 KW

Figure 4-6

ENERGY DENSITY FOR CANDIDATE ENERGY SOURCES

	Higher Heating Value in BTU/lb m	Approximate Cost	100% Efficiency 6" hole - 50 ft in lbs.
Propane	21,669		5.5
Natural Gas	24,100		5.0
Gasoline	20,460		5.87
Kerosene	19,750		6.08
Diesel Oil	19,000		6.3
Organic Compounds	<21,240		>5.65
Super Corroding Alloy	4,947	$620 ($25/lb)	24.3
Lithium Batteries (125 W-hr/lb)	427	$5620 ($20/lb)	281
Lead Acid Batteries (14 W-hr/lb)	48	$7000 ($10.30/cell; $2.80/lb)	2500
Magnesium Batteries	89	-	1350
Silver Cell (45 W-hr/lb)	154	-	780
Carbon-Zinc (19 W-hr/lb)	65	-	1850
Nicads (31 W-hr/lb)	106	$16,930 ($4.60/4.93 oz. cell; $14.93/lb)	1134

Figure 4-7

COMPARISON OF AVAILABLE ARCTIC ELECTRIC POWER SOURCES

TYPE	WEIGHT (lb/W)
Diesel	70×10^{-3}
Gasoline	60×10^{-3}
Fuel Cell	$25\text{-}70 \times 10^{-3}$
Gas Turbine	20×10^{-3}
Thermoelectric	1
Isotope Generator	15-200
Batteries	11-125*
	9.1×10^{-2} to 8×10^{-3}**

* Watt Hrs./lb.

** Pounds per watt of energy expended in one hour

Figure 4-8

MEASURED PENETRATION RATES FOR EXISTING DRILLING TOOLS

The following notes give examples of actual penetration rates for various types of existing equipment. Most of the information is taken from an unpublished report by Mellor *et al.* (1973), which illustrates many of the pieces of equipment that are referred to.

Thermal drills have also been used for boring holes in ice, although they are very inefficient in energetic terms compared with mechanical drills. Electrical hot-point drills usually penetrate at rates not exceeding 60 to 80 per cent of the theoretical rates calculated on the basis of melting with no heat loss. Theoretical penetration rates for lossless melting were given earlier, and some practical heat losses are discussed by Aamot (1967a, 1968). To give an idea of penetration rate, a 2 kW (2.7 hp) electric hot-point can readily bore 2 in. (51 mm) diameter hole at 0.33 ft/min (1.7 mm/sec). Shreve and Sharp (1970) achieved rates up to 0.49 ft/min (2.5 mm/sec) with 2.1 kW on a 2 in. (51 mm) diameter hot-point, while Stacey (1960) reached 0.63 ft/min (3.2 mm/sec) at 2.3 kW (3.1 hp) and 0.5 ft/min (2.5 mm/sec) at 1.8 kW (2.4 hp) for the same size bit. LaChapelle (1963) drilled at 0.30 to 0.33 ft/min (1.5 to 1.7 mm/sec) with 0.22 kW (0.3 hp) on a 0.71 in. (18 mm) diameter hot-point. The 3.625 in. (92 mm) diameter Philberth probe penetrated at 0.16 ft/min (0.81 mm/sec) with 3.68 kW (4.9 hp) input in Greenland (Aamot, 1967b).* One of us has bored 0.73 in. (19 mm) diameter holes to depths of 200 ft (61 m) at a rate of 0.27 ft/min (1.4 mm/sec) with a 0.25 kW (0.34 hp) electric hot-point. W. Tobiasson (personal communication) has bored with a 0.5 kW (0.67 hp), 1.25 in. (32 mm) diameter hot-point at rates of 0.15 and 0.22 ft/min (0.76 to 1.1 mm/sec). On a larger scale, the 6.4 in. (0.16 m) diameter USA CRREL thermal coring drill has penetrated at rates from 0.126 ft/min (0.64 mm/sec) in 0°C ice to 0.104 ft/min (0.53 mm/sec) in ice at -28°C, the input power ranging from 3.5 to 4.0 kW (4.7 to 5.4 hp) (Ueda and Garfield, 1969b). Russian electrothermal penetrators have drilled at 0.38 to 0.49 ft/min (1.9 to 2.5 mm/sec) with 1 to 2 kW (1.3 to 2.7 hp) on a tip diameter of 1.6 in. (40 mm) and at 0.38 to 0.55 ft/min (1.9 to 2.8 mm/sec) with 3 to 4 kW on a tip diameter of 3.1 in. (80 mm) (Korotkevich and Kudryashov, this symposium). Russian electrothermal corers have drilled at 0.16 to 0.25 ft/min (0.83 to 1.25 mm/sec) with 1.5 to 2.2 kW (2 to 3 hp) on a wedge-profile annulus of 3.5 in. (88 mm) inside diameter and 4.4 in. (112 mm) outside diameter, and also at 0.08 to 0.11 ft/min (0.42 to 0.56 mm/sec) with 3.5 kW (4.7 hp) on a flat-base annulus of 5.1 in. (130 mm) inside diameter and 7 in. (178 mm) outside diameter (Korotkevich and Kudryashov, this symposium). The French "bare-wire" thermal corer is reported to have achieved rates up to 0.33 ft/min (1.7 mm/sec) with about 4.1 kW (5.4 hp) on a head boring 5.5 in. (0.14 m) diameter hole and taking 4 in. (0.1 m) diameter core (F. Gillet *et al.*, this symposium).

This page is copied directly from "Ice Core Drilling".

SECTION 5: HEAT TRANSFER ANALYSIS

Study of the literature has indicated that the conventional thermal drill traditionally has relied on natural convection at the point of the drill to achieve melting of the ice. Since this required the transfer of heat across the melt-water interface, the speed of drilling may be low, efficiencies may be less than desired, and the temperature differential between drill and ice may be great enough to introduce problems of reliability.

It became evident in discussion with James Browning (See Appendix 3) that if the melt water could be placed in motion, a "scrubbing" action will result and the temperature drop across the gap between drill and ice greatly reduced. Indeed, the circulating water itself could be heated, in addition to the hotpoint, to achieve more efficient melting. It was further viewed that if melt water, now at an elevated temperature, were to be recirculated, a very efficient drill might result.

A mathematical model of the drill system was then created and was placed on the UNH DEC-10 computer. At this writing, the full validation of the program is not complete, but key conclusions are evident.

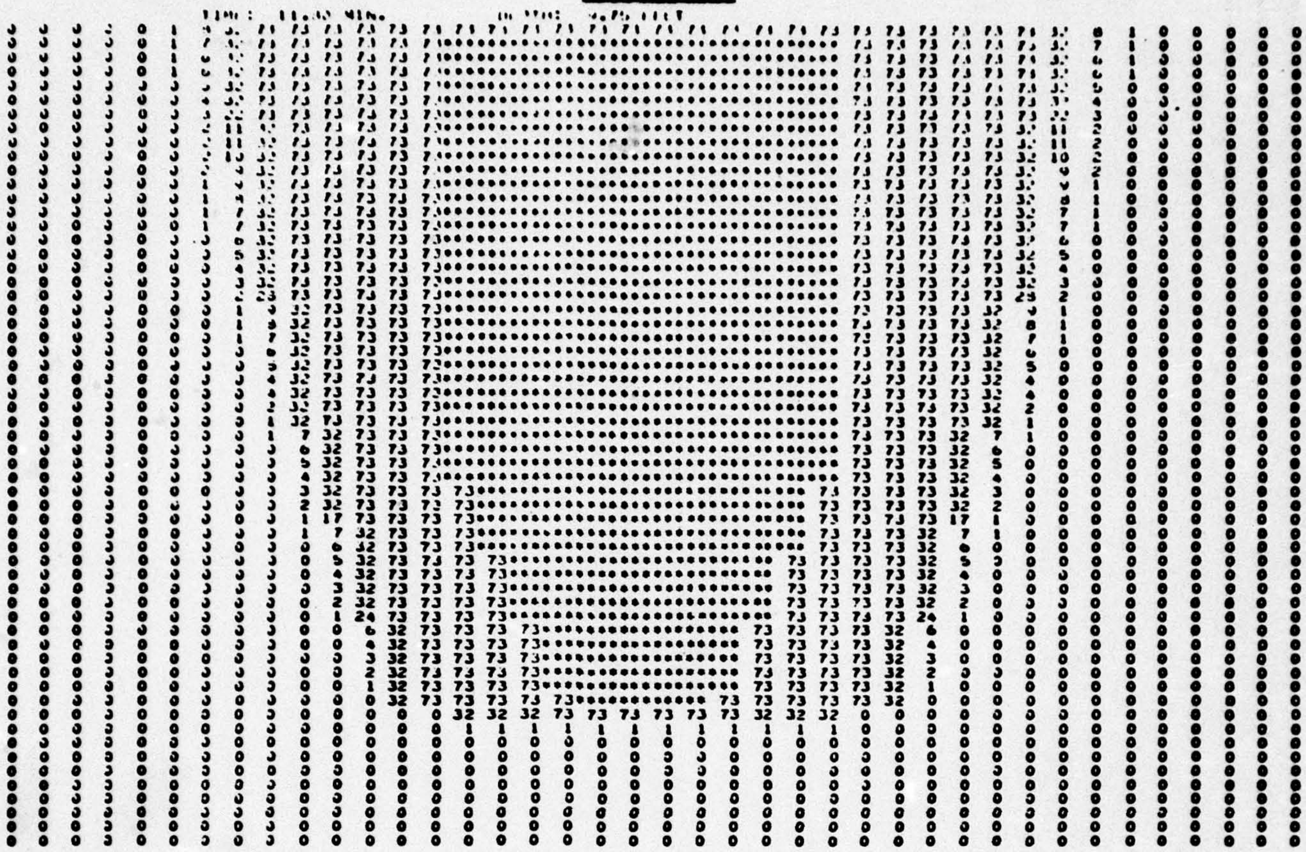
It is clear that the scrubbing drill does indeed drill, that efficiencies are satisfactorily high. A hole is drilled that is perhaps ten times the size of the drill orfice. Total energy and drill speeds appear to be in line with the projections of Section 4.

A thorough discussion of the model, and a review of the computer outputs will be included in a report scheduled for the first of the year 1979.

Figure 5-1 is a sequence of early computer printouts showing the progress of the drill through the ice. The temperature field is indicated.

The ongoing study will produce the physical parameters necessary for drill design. This will then serve as the basis for prototype fabrication.

<u>**Figure 5-1**</u>



```
TIME:  12.01 MINUTES      DEPTH:  9.92 FEET

     DIMENSIONS OF HEATING PROBE:

          OVERALL:
             DIAMETER - 3.00 INCHES
             LENGTH - 12.00 INCHES

          NOZZLE:
             DIAMETER - 1.00 INCHES
             LENGTH -  5.00 INCHES

     INTERPOLATED PROPERTIES OF WATER AT A BULK TEMPERATURE OF  73 DEGREES F :

          DENSITY - 62.267 LBM/CU FT
          VISCOSITY - .6302E-03 LBM/FT-SEC
          CONDUCTIVITY - 0.3490 BTU/HR-FT-F.
          PRANDTL -  6.501

     INPUT PARAMETERS:

          POWER - .1228E+06 BTU/HR
          NOZZLE EXIT VELOCITY - 25.00 FT/SEC
          VOLUMETRIC FLOW RATE -  61.20 GAL/MIN

     JET PARAMETERS (BELOW ELEMENT NO. # 50 ):

          NONDIMENSIONAL CHARACTERISTICS:
             REYNOLDS - .2059E+06
             NUSSELT - .2634E+04
          AVERAGE HEAT TRANSFER COEFFICIENT:
             H - .1103E+05 BTU/HR-SQ FT-F.

     ANNULUS PARAMETERS (AT ELEMENT ROW # 1):

          VELOCITY -  2.78 FT/SEC
          NONDIMENSIONAL CHARACTERISTICS:
             REYNOLDS - .6M62E+0[illegible]
             NUSSELT - .4352E+0[illegible]
          HEAT TRANSFER COEFFICIENT:
             H - .6975E+03 BTU/HR-SQ FT-F.

     DIAMETER AND VOLUME OF HOLE:

          DIAMETER - 6.00 INCHES
          VOLUME - 3.1366 CU FT
```

SECTION 6: THE CONCLUSIONS AND EXPERIENCES OF THE BROWNING ENGINEERING CORP.

Mr. James Browning, formerly of Dartmouth College and CRREL, founded his Corporation in 1961 devoted to jet drilling in rock and ice. His work in the Antarctic in jet drilling through 1380 feet of ice in late 1977 is described in Appendix 3. Mr. Browning has consented to serve as a consultant to this program and prepared two reports. These are characterized by inventiveness and insight, which are included in Appendix 3.

The Browning influence on the thinking of the project has been substantial. His views of the steam-jet, and the hot-water jet generated the thinking that lead to the "scrubbing" concept and to the subsequent thermodynamic modeling mentioned in Section 5. His discussions have proved most valuable in setting *decision criteria.* Appendix 3 makes excellent background reading.

Included also are copies of literature describing the Browning drill which were adapted to the Antarctic drilling experiment.

SECTION 7: THE IMPACTOR SYSTEM

The impactor, as developed by Sandia, is a device of a given mass that is deployed from an aircraft, reaches terminal velocity, and on impact, plunges into the terrain below. References #76, 77, 78, and 79 discuss Sandia experience in designing penetrators of sea ice. In the ADOM application it would rely on a shaped missile hitting the ice at maximum possible velocity, perforating the ice, and continuing upon penetration to serve as an anchor for the instrument string.

It is noted that a divergent requirement is immediately evident. Maximum landing force is required for the impactor, minimum landing force for the highly sophisticated ADOM instrument - computer - communication and antenna package. The two system elements, moreover, must remain joined by a cable throughout deployment. This implies that they must land at far different speeds, in different places, at different times with possibly great loading on the cable. This is viewed as a most difficult task, if system reliability is to be assured.

Dr. C. W. Young of Sandia has developed equations, containing empirical constants, which represent their experience with sea ice penetration. This data has been extrapolated here in the Arctic-ADOM problem.

From the referenced report "A Parametric Study of an Ice Penetrating Sonobuoy Vehicle" -- C. W. Young, Terradynamics Division, Sandia Labs 1972 Report SC-DR-720379, the following equation was drawn:

$$D = 0.0031\ SN\sqrt{W/A}\ (V_1 - 100)$$

S = index of penetrability; recommended value = 2
N = nose cone performance coefficient; best value = 1.32
W = weight in pounds
A = area in square inches
V_1 = entry velocity in feet per second
D = depth of penetration in feet

Several key footnotes to this equation are in order:

- A key design parameter is the ratio W/A -- the weight divided by the cross-section area. Weight W is:

$$W = d \times A \times L$$

where d = density, A = area, L = length.

The equation for penetration, D, thus becomes

$$D = .0031\ SN\sqrt{d \times L}\ (V_1 - 100)$$

We see, then, that penetration is unrelated to size. i.e., cross-section area of the missile. A little one penetrates as far as a big one!

- The referenced report notes that there is a maximum length L which may be tolerated. If L exceeds 18 times the diameter, the impactor fails to have ample mechanical strength to inhibit bending, using available metals.
- There is a limit to the practical density that may be employed. They used a combination of lead and steel with a maximum weight to area, W/A, ratio of 20.
- The velocity, V_1, in free fall reaches a limit of roughly 600 feet per second.

Figure 7-1 illustrates the depth of penetration for various sizes of impactors as weight increases. It is noted that all reach the same maximum depth of 17 feet (5.2 m) in typical sea ice with an optimum shape of nose cone, and a lead/steel construction.

Obviously, this is inadequate in view of the anticipated ice depths. The velocity may be increased above free fall terminal velocity, however, by addition of a jet booster. Figures 7-2 and 7-3 examine the performance with 1.6 and 2.5 times terminal velocity. Penetrations of 33 feet (10 m) and 51 feet (15.5 m) were shown.

The decelerations encountered by the penetration through 30 feet of ice, given linear loading, may be calculated.

Velocity of Impact	Approximate G (for 30' of ice)
600 feet per second	130 G
1000 feet per second	217 G
1500 feet per second	325 G

Decelerations of 600 G were found in the Sandia probe, in a free-fall descent, and penetrating 6.5 feet. The instrument package suffered substantially higher G's since it had, at best, one foot in which to decelerate.

The problem of a soft landing for an instrument package, tethered to a jet-propelled impactor, offers no easy solutions. The penetrator presumably would pull 1500 m. of instrument cable, housed either in the companion package or the probe, over the ice and down the hole.

On full deployment, the cable, attached to the instrument package somewhere nearby, must support the full weight of the anchor and 1500 meters of instrument cable. This places extraordinary demands on the cable specifications.

Note is made that the instrumentation package, alternatively, might hard-land on the ice behind the impactor. This implies a deceleration from 2200 fps. to zero in some distance like one foot. This creates acceleration loadings in excess of 30,000 G, an overwhelming assignment for a developmental computer, a self-erecting satellite antenna, and interface electronics.

The impactor approach is faulted for placing a very substantial reliability demand on top of a difficult basic system development.

Figure 7-1

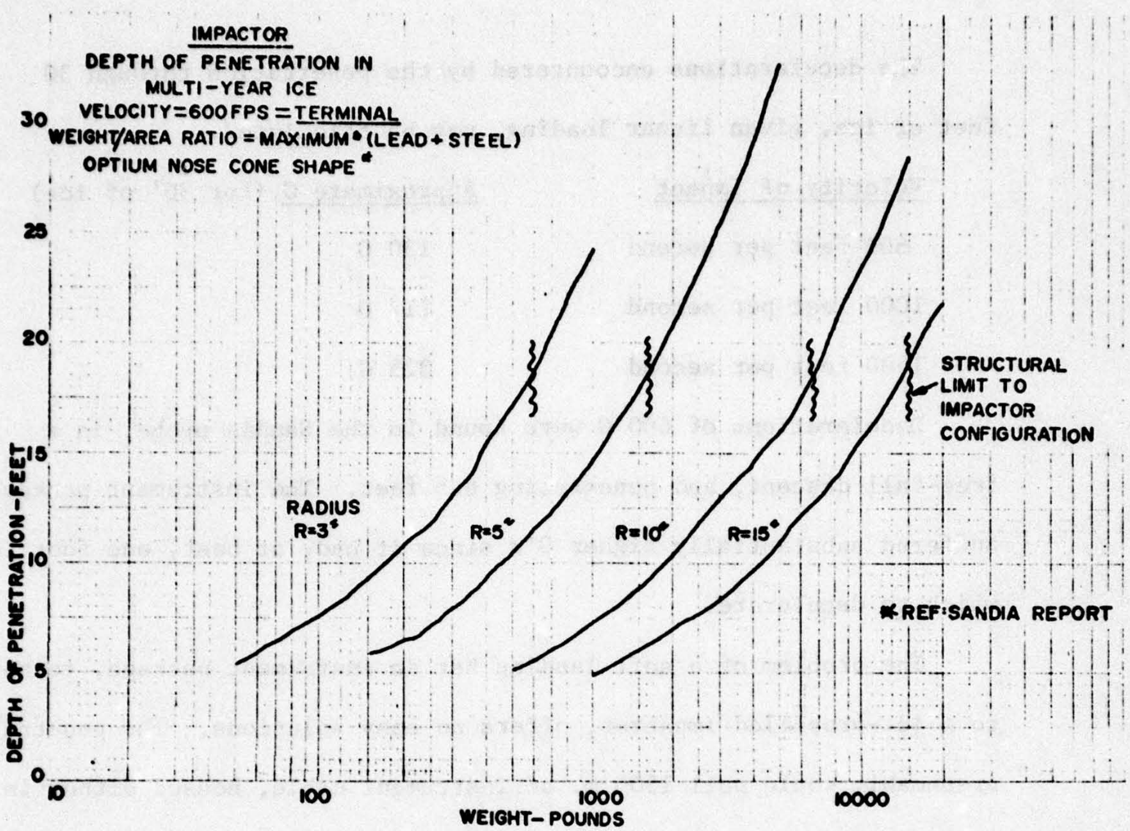


Figure 7-2

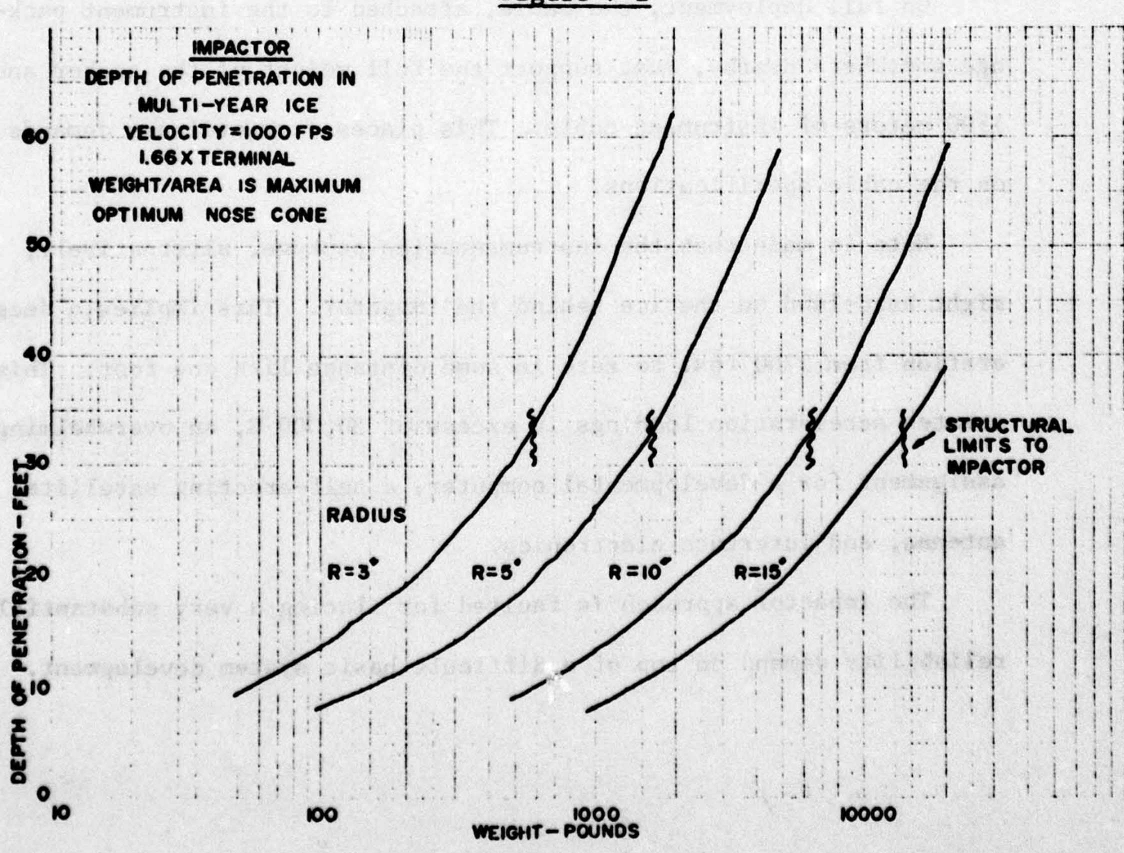
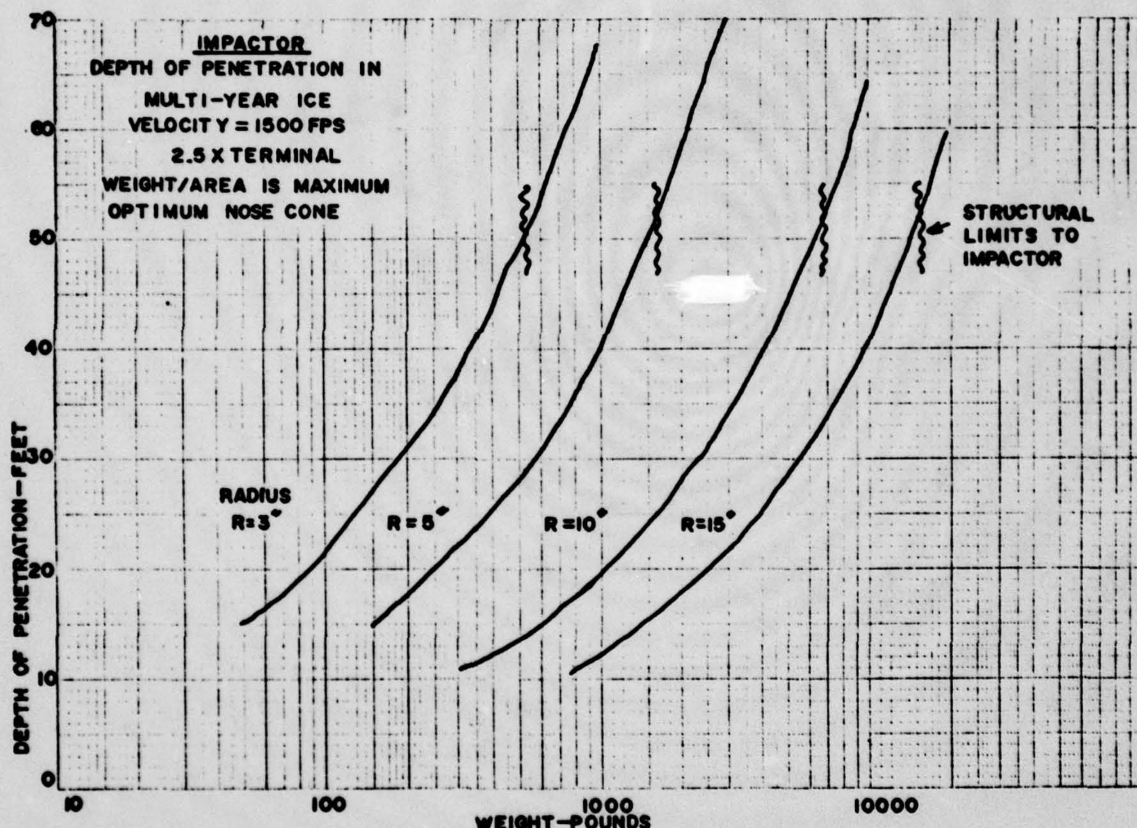


Figure 7-3


IMPACTOR
DEPTH OF PENETRATION IN
MULTI-YEAR ICE
VELOCITY = 1500 FPS
2.5 X TERMINAL
WEIGHT/AREA IS MAXIMUM
OPTIMUM NOSE CONE
STRUCTURAL
LIMITS TO
IMPACTOR
RADIUS
R=3"
R=5"
R=10"
R=15"
DEPTH OF PENETRATION-FEET
0
10
20
30
40
50
60
70
10
100
1000
10000
WEIGHT-POUNDS

SECTION 8: AN OVERVIEW OF MECHANICAL DRILLING

Introduction

In general, mechanical drilling in ice is an attractive low energy concept for a reduction as much as an order of magnitude in energy required over thermal drilling. Data in an early ADOM Progress Report suggests that this has long been considered as an attractive alternative (See Figure 8-1).

There are many successful mechanical drills, including ice augers available at local hardware stores. All existing drills require manned-support systems; no remotely, unmanned mechanical drills have been developed. An excellent reference on ice drilling is available in a 1974 Symposium on the subject. (Reference #60)

On an energy basis, mechanical drilling is clearly the optimal method. The serious problem arising for mechanical drilling, however, is drill bit head stabilization, (i.e., control of cutting head orientation and cutting head interface forces). Two leading methods (i.e., telescoping drill and a mechanical "mole") suffer serious drawbacks. One either must provide the power from the surface and transmit it to the drill head via some telescoping/torque transmitting shart which can grow to 50 feet in length, or one must carry the motor in a "mole" drill head which is stabilized in the hole with torque resisting and downward moving mechanisms (such as tracker treads). Both are complex and have many moving parts.

Experimental Data

The best summary of actual data on drilling rates and power is provided by Mellor and Sellman in "Ice-Core Drilling". It is valuable enough to be included directly in Appendix 5.

Background

The basic considerations in mechanical drilling are:

1) The cutting process and the energy requirements

2) Removal of surplus materials

3) Stabilization of cutting head

The Cutting Process

In a mechanical drill, a certain amount of energy is needed to cut or chip the material; this is often called the "specific energy for cutting" -- the work done per unit volume of material cut. The minimum value this can assume is the fracture surface energy of the material multiplied by the specific area of the cuttings. This minimum can easily be calculated from:

$$P_c = 1.98 \times 10^{-6} D^2 R E_s (H_p)$$

where D is hole diameter in inches
R is the drilling rate (in/min)
E_s is the specific energy (in lb/in^3)

Many experiments to determine E's have been made for ice and other natural arctic material. E_s ranges from about 70 in lb/in^3 to 700 in lb/in^3 depending on temperature, cutting rates, cutting technique. Data for these follow.

For drilling a 6 inch hole, 50 feet deep in one hour, the requirement is approximately 4 hp as a minimum, if the specific energy is 700 in lb/in^3. Conservatively, it would probably require 6 Hp or so. This is about one-tenth the power required for thermal/melting systems.

Power to Remove Cutting

The power to remove cuttings is a small portion of the total power required. A calculation based on 50 feet/hr, and a six inch hole indicates that this power is approximately 0.1 hp. The relationships of hole size, power, and drilling rate are shown in Appendix 5.

Figure 8-1

ICE DRILLING COMPARISON

ICE CONDITION	FREE FALL PENETRATIONS	SOFT LANDING	
		MECHANICAL DRILL	THERMAL HOT POINT DRILL
OPEN WATER 1-10% probability	would need flotation device no drilling equipment required		
FIRST YEAR UNDEFORMED ICE 15-20% probability ~ 1.5m	weight = 43 kg length = 1.9m diameter = 8 cm velocity = >100 m/s drop altitude = >2400m Technology already available; see Young, C.W., 1973 Development of an Ice Sonobuoy Penetrator (U) Sandia Laboratories, Albuquerque, N.M. 87115 Considerations: (1) selection of drop zone required (2) acceleration forces on electronics and cable (3) hole larger than 4 cm	weight volume time to drill = 6 min energy consumption = 1.3×10^5 J Considerations: (1) good for large or small holes (2) drill must be leveled (3) antifreeze must be preheated aboard aircraft	weight volume time to drill @ 12 cm/min = 12 min energy consumption = 1.1×10^6 J
MULTI-YEAR UNDEFORMED ICE ~ 3.0m 20-40% probability	weight = 43 kg length = 1.9m diameter = 8 cm velocity = >100 m/s drop altitude = >2400m Considerations: (1) acceleration forces on electronics and cable (2) will also operate in first year ice (3) hole larger than 4 cm	weight volume time to drill = 11 min energy consumption = 2.6×10^5 J Considerations: (1) must be leveled (2) new technology (3) antifreeze must be preheated aboard aircraft	weight volume time to drill @ 12 cm/min = 25 min energy consumption = 2.2×10^6 J Considerations: (1) some leveling of drill required
DEFORMED ICE Ice keels, 3-8m Top surface undulating 30-40% probability	weight = 900 kg length = 3.6m diameter = 35 cm velocity = 300 m/s drop altitude = 3-5000m Considerations: (1) new technology (2) acceleration force will break currently available multi-conductor cable (3) maximum penetration at 300 m/s = 5m (4) hole larger than 4 cm	weight = 680 kgs volume = 1 m^3 time to drill = 30 min energy consumption = 6.8×10^5 J Considerations: (1) rough surface may prevent leveling (2) new technology (3) antifreeze must be preheated aboard aircraft	weight volume time to drill @ 12 cm/min = 1 hr energy consumption = 1.2×10^7 J Considerations: (1) rough surface may prevent leveling

Values are tentative and subject to revision as a result of further analysis and firmer operating parameters.

NOTES: (1) Pertains to drilling 4 cm hole, except for free fall penetrator whose hole will correspond to its diameter.
(2) Weight and cube values include power source, cable drill mechanism, leveling mechanism. Excluded are packaging and electronics.

Data from ADOM Progress Report (August 1977)

SECTION 9: SUMMARY OF DRILLING SYSTEM ALTERNATIVES AND THE APPLICATION OF DECISION CRITERIA

1. Introduction

A chart, "Potential Arctic/ADOM Ice Drilling Systems", is shown as Figure 9-1. It lists the 87 possible candidates that have won our consideration as candidate drills. They are grouped in four generic systems (plus a tactical solution). They involve eleven systematic approaches and rely on an over-lapping group of some 15 potential sources of energy.

The 87 candidates involve some combinations that are openly impractical, and some which may include a major flaw that merits immediate rejection, or indeed, causes it to be less effective than others under review. We have engaged in a four stage filtering process to eliminate candidates:

A. Examination of the several identified power sources to eliminate those found to be inappropriate for various reasons.

B. Examination of the over-all system concepts, and, where appropriate, identification of fundamental weaknesses is made.

C. A listing of the systems that remain is then made, combining the various surviving power sources, and systematic approaches. These systems, then were measured against a set of criteria that grew out of the ADOM Committee Meeting of April 17, 1978. These criteria are listed in the order suggested by the Committee, but are not weighted. The resulting judgements are shown in a chart titled "ADOM Project Design Decision Matrix". See Figure 9-1.

D. The surviving systems are then discussed in Section 10, where a point-by-point review of their merits is presented.

It is observed that while the summary conclusions offered and their justifications are listed below in a very brief form, a volume of data, as well as related studies, do exist to back up these conclusions in most instances. They are not included for reasons of volume.

2. <u>Power Source Examination</u>

An examination of the various power sources listed in Figure 9-1 resulted in the following decisions:

- <u>Solar Energy</u>: Solar energy is not available in the Arctic many months of the year. Rejected.
- <u>Nuclear Energy</u>: Strict regulations exist on dispersing and discarding nuclear power sources. Rejected.
- <u>"Hot Bricks"</u> and <u>"WANGANOL"</u>: Inadequate data is available to us on these systems to make a detailed judgement. They are known to be composed of chemicals under consideration elsewhere in the list. They are rejected, with the proviso that they would be re-examined if the constituent chemicals become prime candidates for consideration.
- <u>Electric Generators</u>: Motor generators are often difficult to start and to maintain in the Arctic environment, and they have many moving parts. Although specifically designed motor generators may be adapted for Arctic/ADOM, they are viewed as an unreliable and ineffective way to obtain a short term burst of some 80,000 BTU of controlled power. Rejected.
- <u>Fuel Cells</u>: Fuel cells are temperature sensitive and, moreover, are designed to provide a modest energy drain over an extended period, as opposed to the Arctic/ADOM requirement of a peak drain of tens of KW for a short period. Rejected.

3. System Configuration Examination

The chart of Potential Arctic/ADOM Ice Drilling Systems listed 4 generic systems with several subsystem variations. In addition, the tactic of Open Lead Deployment was mentioned for completeness, although this approach is under study by the Polar Research Laboratory and, therefore, not considered as an ADOM alternative. These systems were reviewed as follows:

Impact Penetrometer

The specified maximum depth of ice that must be penetrated requires that a penetrator have a velocity in excess of its free-fall terminal velocity. This requires a jet-assist during the fall. Conflicting requirements exist for a minimum landing acceleration for the instrument package and a maximum deceleration for the penetrometer portion of the system. This implies that widely different velocity-distance profiles will exist for each section of the system as it descends, causing them to land possibly some distance apart. They must remain connected by cables, however, which will be placed under substantial stress.

The system is rejected on grounds of complexity and reliability.

Mechanical Drills

Manned mechanical drills have a proven record of success in the Arctic and they are very efficient in the use of energy. Translation of manned technology to the Arctic/ADOM problem, however, is not direct. Packaging a 50 foot telescoping drill stem in the space available in ADOM, for example, is a major challenge. The development of a mechanical MOLE is similarly complicated. Steering of either system requires new technology development. The systems are rejected on grounds of survivability, reliability, and the extensive development needed to achieve a satisfactory unmanned operation.

Thermal System - Convective

Thermal systems have a long and successful history of manned drilling in the Arctic, basically employing a convection-based, or non-scrubbing, hot point.

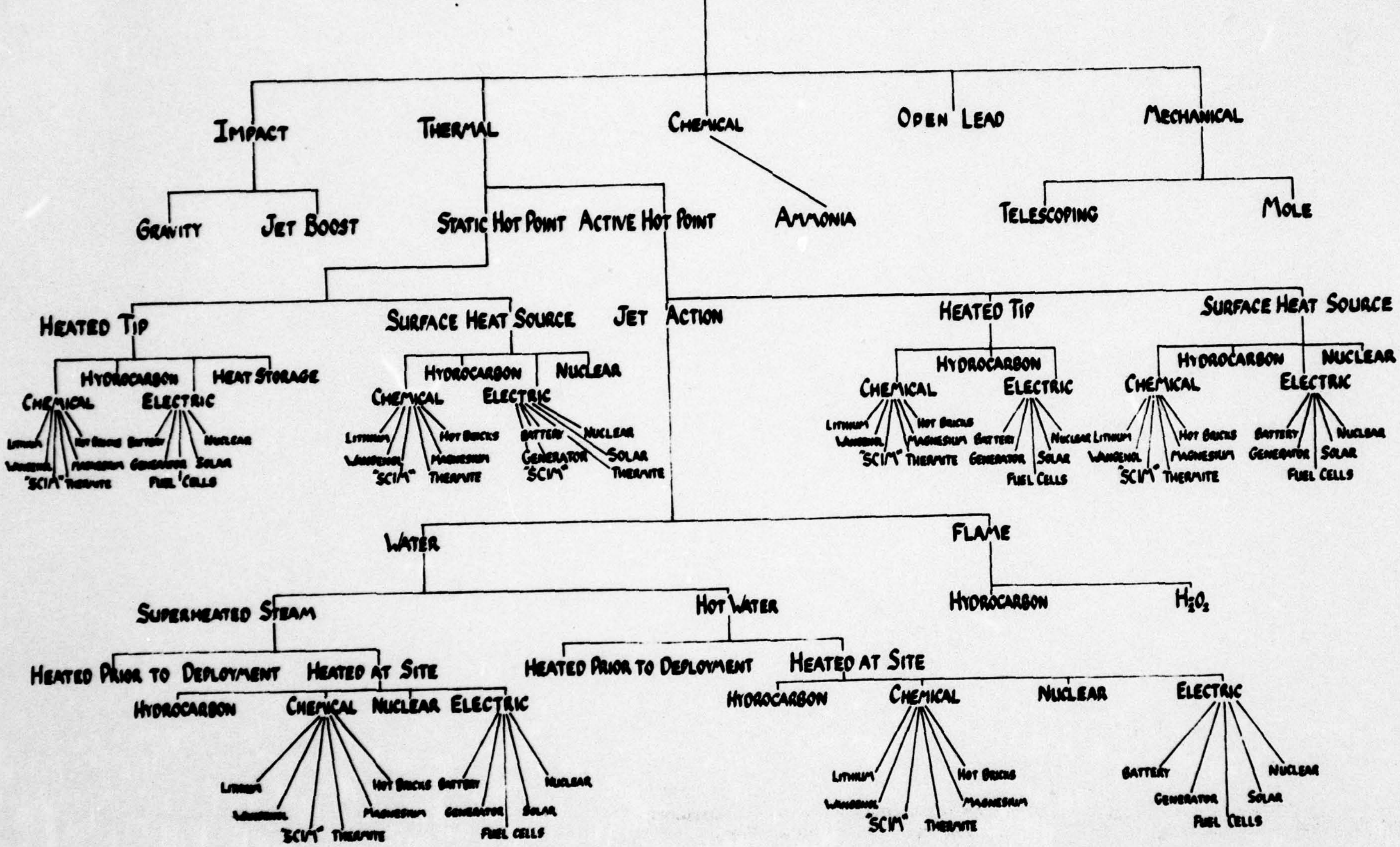
Thermodynamic analyses, however, described elsewhere in this report, are proving that the conventional hot point will drill more slowly, and is less efficient than the "active" or scrubbing system, or the hot water jet system. The cost in reliability to achieve scrubbing or jetting is deemed low, since the technology appears to have been proven in the field. The entire generic branch of systems labeled static hot points is rejected on grounds of the speed of drilling and the low cost required to achieve improved thermodynamic efficiency through scrubbing.

Thermal System - Surface-heated Working Fluid

Heat may be transferred to the hot-point via a working fluid heated on the ice surface. This approach was rejected on the ground of unnecessary heat losses in transmission and the practicality of the competing systems that generate heat in the probe, plus the added weight and complexity that the system entailed.

Figure 9-1

POTENTIAL ADOM ICE DRILLING SYSTEMS



SECTION 10: SYSTEM REVIEW

The above decisions winnow the 87 systems initially named to 23 candidate systems which are shown in the chart as Figure 10-1. These 23 systems were not discarded by the first level of criteria, and consequently have been selected for examination in further detail. The summary judgements made on each are described below. The analyses which accompanied these viewpoints, in most cases, are not included.

- Battery Heated Hotpoint with Scrubbing

Hotpoint is electrically heated with battery power. A pumped flow of water (melt water) carries the heat to the ice. System accepted for further review.

- Hydrocarbon-heated Hotpoint with Scrubbing

Fuel oil is burned in the drill itself to heat the hotpoint. Excellent efficiency of fuel and its low cost is out-weighed by problems of getting oxygen to the down-hole burner, and by the need for near-perfect reliability of burner start-up on command. Rejected.

- Ablative Rod of a Super-corroding Alloy (Described in Appendix 4)

An ablating rod of the NCEL Supercorroding Alloy is surrounded by a forced flow of water that conducts heat to the ice and that carries away the bubbles formed in the process. System calculations indicate that a ¼" rod, 40" long contains enough heat for a 50', 6" hole. System is rejected for immediate development due to too many fundamental unknowns to merit Phase II prototyping. The technology is viewed as worthy of consideration as an R&D program.

- Lithium and Magnesium Heat-tip with Scrubbing

Same disposal as the Super-corroding allow. Research is required before development should be started. Viewed as less promising than the NCEL alloy. Rejected.

- Prior-heated Steam Jet

If a tank of super-heated steam were to be loaded into the Arctic/ADOM initially <u>before</u> aircraft take-off, and if maintained at high temperature during flight, a very simple system results. (See Browning Report, Appendix 3.) The system is rejected, however, because the residual water existing in the steam-tank poses a hazzard in a 100 G landing, and thus a threat to system survival. Moreover, the insulated pressurized tank required takes up an excessive volume of system space, and could limit its use on a P3 aircraft.

- Battery Powered Steam Jet

The steam jet would be generated by battery power after deployment. This was found to be inefficient use of battery power. Water temperature for efficient drilling need not exceed 212°F, and the jet force, if required, may be obtained more efficiently in other ways than boiling water.

- Hydrocarbon Steam Jet

Here, the steam would be generated by burning hydrocarbons in a boiler that remains on the surface and would create a jet against the ice. This steam drill employs the high energy content of fuel oil and the attractiveness of the jet, but does not relieve the reliability concerns related to starting up an unmanned oil burner, or an

evolving concern about the efficiency of steam jets.* An added option does exist for placing the boiler down-hole in the probe. Rejected for reliability reasons, with a reservation that the system be re-examined if reliability concerns are relieved and if steam-jets are found to be as efficient as hot water jets.

- Steam Jets Powered by Chemicals

Four steam jets powered by chemicals as shown on Figure 10-1 have been examined. All have potential, but none were deemed ready for prototype construction. They are rejected for immediate construction, but reserved for R&D consideration.

- Prior-heated Hot-Water Jet

This system is similar to the steam jet, but involves lower temperature, a larger quantity of water, less pressurization requirements, and a requirement for a compressed air tank to form the jet. It assumes that the water is heated before the aircraft takes off, and that temperature is maintained in flight. Rejected for its large size, and for poor chance of surviving under high G landing conditions.

- Battery-powered Hot-Water Jet

The battery heats, and recirculates, melt water, pumping it as a high velocity jet directly onto the ice interface. The system is selected for continued review.

---

* See Heat Transfer Study of Section 5, and the detailed report to be published. Initial indications are that the more efficient jet is elevated in temperature only a limited number of degrees.

- Hydrocarbon-fueled Hot Water Jet, recirculating melt water

Rejected due to concern about reliability of a down-hole boiler and the problems of supplying air to the boiler.

- Chemically Heated Hot Water Jets

All heating chemical systems require further study and development before applying to Arctic/ADOM's. Rejected as unsuitable for early system development.

- Hydrocarbon Flame Jet

The direct burning of hydrocarbon and air, under pressure, produces an intense flame. Temperatures run high, and heat transfer to the ice is poor. High temperatures cause high potential for nozzle corrosion. One was used successfully for a deep Antarctic hole. See Appendix 3. System rejected due to problems of potential corrosion, nozzle cooling, and poor heat transfer.

- H_2O_2 Flame Jet

The burning of hydrogen with oxygen produces an intensive flame at high temperature. Studies show that the thermodynamic need is for a modest jet temperature to melt the ice with efficiency. System rejected for same reasons as the Hydrocarbon flame jet, with the added cause that the fuel is dangerous to handle.

- Ammonia

Anhydrous ammonia is a chemical that interacts directly with ice, producing unstable hydrides of ammonia. The system requires substantial heat to be supplied to vaporize the ammonia. The volume of gas required is larger, and the efficiency of drilling appears to be low. Rejected.

Summary of System Selection

Employing the criteria that a technology must be found that is capable of early prototyping with a high probability of success, we discarded several attractive candidates in favor of manageable technology.

The final conclusions, resulting in rejections in several cases, continue to hinge on completion of the Heat Transfer Analysis Study. This investigation, incomplete at this writing, is providing a strong basis for a system that achieves an optimum transfer of heat to the ice.

The systems that survived the selection process are:

- A battery-heated hotpoint with scrubbing action by recirculating melt water.
- A battery-heated hot water jet.

Note is made that the two systems that were selected for development, each stemming from a different line of technology, are indeed very similar. They differ primarily in nose cone configuration, a design detail. Computer modeling is in progress at this writing to determine if the drill should be a jet nozzle, or a heated hot-point cone accompanied by a jet of melt water.

Figure 10-1

ADOM PROJECT DESIGN DECISION MATRIX
(FINAL)

	BATTERY HEAT TIP W/SCRUB	HYDROCARBON HEAT TIP W/SCRUB	"SCIM" (ABLATIVE) HEAT TIP W/SCRUB	LITHIUM HEAT TIP W/SCRUB	THERMITE HEAT TIP W/SCRUB	MAGNESIUM HEAT TIP W/SCRUB	PRIOR HEAT STEAM JET	BATTERY STEAM JET	HYDROCARBON STEAM JET	"SCIM" (HEAT) STEAM JET	MAGNESIUM STEAM JET	LITHIUM STEAM JET	THERMITE STEAM JET	PRIOR HEAT HOT WATER JET	BATTERY HOT WATER JET	HYDROCARBON HOT WATER JET	"SCIM" HOT WATER JET	MAGNESIUM HOT WATER JET	LITHIUM HOT WATER JET	THERMITE HOT WATER JET	HYDROCARBON FLAME JET	H_2O_2 FLAME JET	AMMONIA
RELIABILITY	✓	?	?	?	?	?	✓	✓	?	?	?	?	?	✓	✓	?	?	?	?	?	?	?	✓
COMPATIBILITY WITH ADOM	✓	✓	✓	?	✓	✓	✓	✓	✓	✓	✓	?	✓	✓	✓	✓	✓	✓	?	✓	✓	✓	✓
SURVIVABILITY	✓	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓	✓	✓	✓	X
SIZE	✓	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓	✓	✓	✓	X
WEIGHT	✓	✓	✓	✓	✓	✓	?	✓	✓	✓	✓	✓	✓	?	✓	✓	✓	✓	✓	✓	✓	✓	✓
ENVIORMENTAL IMPACT	✓	✓	✓	?	✓	✓	✓	✓	✓	✓	✓	?	✓	✓	✓	✓	✓	✓	?	✓	✓	✓	✓
ENERGY REQUIREMENT	✓	✓	✓	?	X	X	✓	X	✓	✓	?	?	?	✓	✓	✓	✓	?	?	?	✓	✓	✓
COMPLEXITY	✓	X	✓	?	?	?	X	✓	X	?	?	?	?	X	?	X	?	?	?	?	X	X	✓
DEVEL. TIME	✓	✓	R+D	R+D	R+D	R+D	✓	✓	✓	R+D	R+D	R+D	R+D	✓	✓	✓	R+D	R+D	R+D	R+D	✓	✓	R+D
FIELD TEST COST	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DEVEL. COST	✓	✓	R+D	R+D	R+D	R+D	✓	✓	✓	R+D	R+D	R+D	R+D	✓	✓	✓	R+D	R+D	R+D	R+D	✓	✓	R+D
PROD. COST	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DEVEL. RISK	✓	✓	R+D	R+D	R+D	R+D	✓	✓	✓	R+D	R+D	R+D	R+D	✓	✓	✓	R+D	R+D	R+D	R+D	✓	✓	R+D
MEETS DESIGN SPECS.	✓	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓	✓	✓	✓	?
	(1)		(3)												(2)								

X - Rejected

R&D - Technology may be potentially acceptable but development is needed before it could be used in a Phase II prototype.

? - Inadequate information is available. On systems accepted, this implies that the unknown is judged not to be a major obstacle to development.

✓ - Acceptable performance.

SECTION 11: SYSTEM CONSIDERATIONS - BATTERY POWERED HOTPOINT (WITH SCRUBBING)

The investigation of the eighty-seven system configurations which were considered led to two candidates for the Arctic/ADOM ice drilling system, each stemming from a different line of technology. One system employs hot water heated by an electric heat source, which is flushed at high velocities from the nose cone of the hot point. This is known as the hot water jet system. The second system uses water which has been electrically heated to scrub the ice in front of the hotpoint. On close examination, however, it is seen that both systems have similar characteristics. The only substantial difference is the design parameter of the velocity of the water around the hot point heating source and the configuration of the hot point. Since the two systems are very similar, the continuing heat transfer computer modeling will be used to find answers relative to each of the two systems. The relative merits of their differences will be explored prior to a design commitment.

The chosen system is examined below in terms of its anticipated performance, advantages and problem areas. The topics are the design goal headings selected by the ADOM Committee.

Development Risk: Least risk of the group that was studied.

Reliability: The battery systems seem initially to be the most reliable of all systems in that they are so inherently simple, the only complexity being an on/off device which will allow thermostatic control of the hotpoint during times of thermal mismatch when a need exists to eliminate overheating problems.

Compatibility: A battery system is indeed compatible with the existing ADOM system components; in fact, it is possible to use any remaining energy after the drilling process is finished to power the remainder of the ADOM system.

Survivability: The proposed battery system can be made structurally survivable under the specified 100 G impact loading due simply to its rugged construction and its lack of moving parts. Design effort will be needed, however, to secure the hotpoint during impact due to its mass.

Size & Weight: Initial calculations of energy density and hotpoint volume show very little need for concern in meeting the constraints for packaging to be carried on the P3 aircraft. More work must be done relative to the actual interface and space requirements of other ADOM system components.

Environmental Impact: The battery system is an inherently "clean" system.

Energy Requirements: Theoretical analysis of energy requirements to drill a 6" hole in 50' of ice dictate energy levels on the order of 120,000 Btu's. Considerations of actual energy density of Lithium batteries indicate that within the Arctic/ADOM package it may be possible to store upwards of 150,000 Btu's with relative ease.

Complexity: The battery systems, after considering many alternatives, seem to be the least complex. Indeed, this characteristic makes this type of system very attractive for automatic operation.

Development Time & Cost: Since battery technology has been developed to a stage where reliability is bought and paid for, a piece of the development effort has been simplified. Along these same lines, it is possible to take advantage of a substantial amount of work which has been done with hot-point design. For these reasons, it may be possible to lower the actual development costs in both time and money.

Figure 11-1 is a sequencing diagram of the operations performed in deployment.

Figure 11-2 is an initial concept of the Arctic-ADOM package involving the scrubbing hotpoint concept. The erection system shown has not been studied in depth.

In Figure 11-3, a cost trade-off is presented that has useful implications. As the design limit for penetration in sea ice increases from 30 to 50 feet, the cost of each system rises markedly, due to the expense of the added Lithium batteries. The likelihood of encountering ice of a given thickness, however, decreases as the design limit increases. Obviously, to design for a 100% probability of penetration is expensive, and it also is expensive to expend a number of cheaper systems against the prospect of encountering areas of thinner ice. In Figure 11-3, the cost of achieving 20 successful penetrations, assuming more than 20 attempts, is shown as a function of the designed penetration limit of the system. Two system variations are considered. The battery cost, plus $15,000 for the rest of the system, and the batteries plus $20,000. In both

cases, cost reaches a minimum if the drill is designed for only 35 feet (10.66 m) penetration, even though a 50 foot thickness might be encountered.

If the system reliability, independant of ice thickness, is .95, the character of the curve remains the same, except that more units must be deployed to achieve 20 penetrations. If 100 penetrations, rather than 20, are accomplished, the optimum design limit for minimum cost still remains 35 feet, as shown in Figure 11-4.

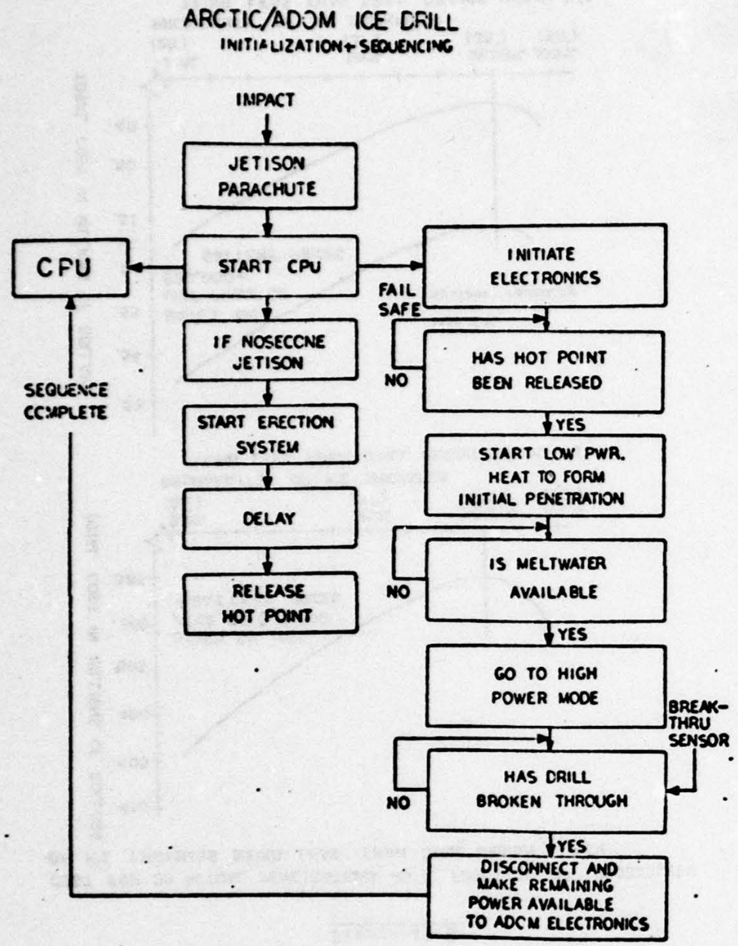


Figure 11-1

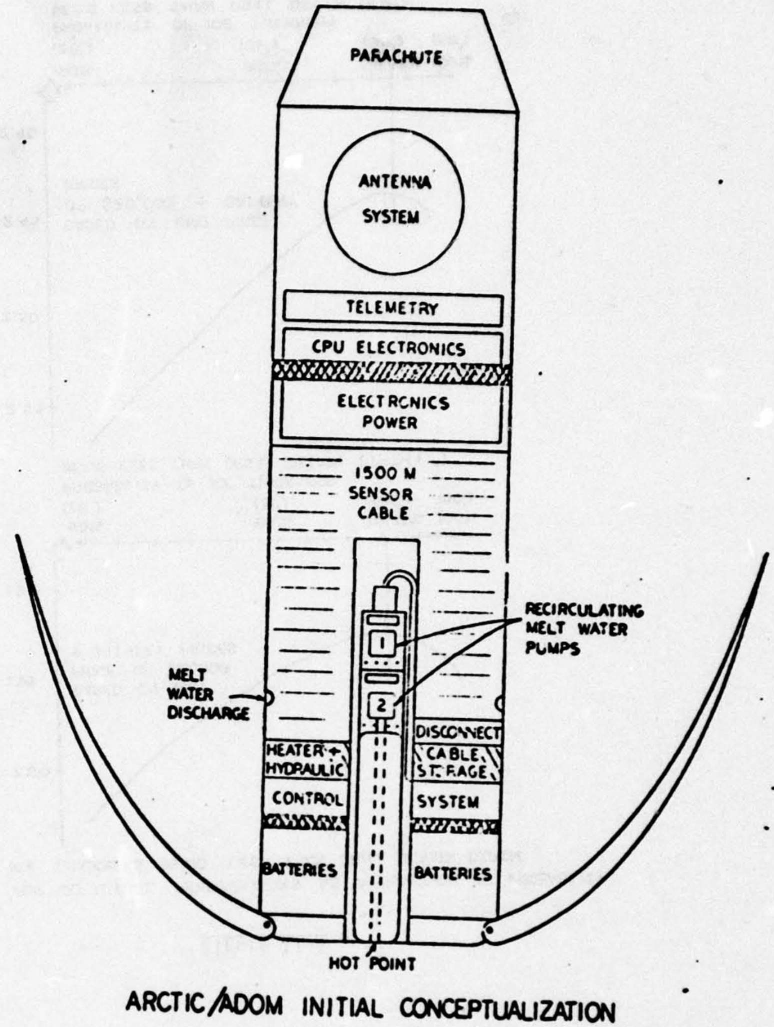


Figure 11-2

Figure 11-3

COST FOR 20 ACTUAL PENETRATIONS AS A FUNCTION OF PROBABILITY OF ICE THICKNESS BEING LESS THAN DRILL DESIGN DEPTH

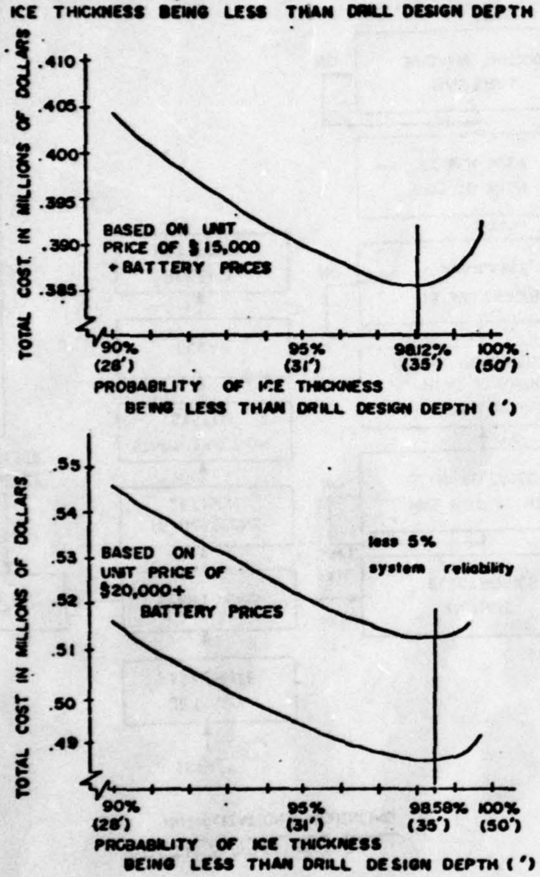
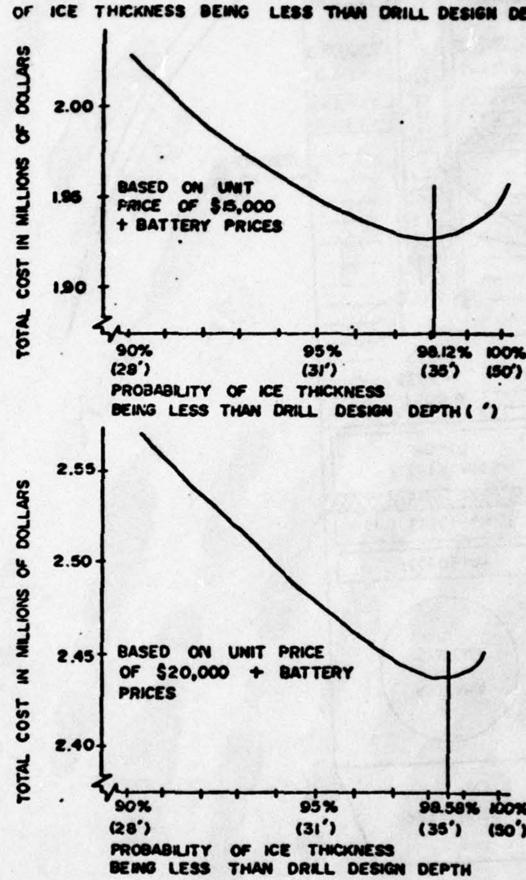


Figure 11-4

COST FOR 100 ACTUAL PENETRATIONS AS A FUNCTION OF PROBABILITY OF ICE THICKNESS BEING LESS THAN DRILL DESIGN DEPTH



SECTION 12: DEVELOPMENT PLAN - PHASE II

The task statement for Phase II, issued at the start of the program, states:

The outcome of the Phase I effort will be a definitive recommendation for a system to penetrate the ice-covered ocean in a manner consistent with the ADOM Program objectives. Following approval of a Phase II program by the ADOM Committee and ONR, an effort to design, develop and test a prototype of the ice penetration system will be started. The purpose of Phase II is:

> To conduct detailed technical studies of the recommended penetration concept, to design and develop a working prototype of the penetration system (devoid of air deployment hardware, electronics and sensors but compatible with the other components of ADOM) and to conduct preliminary tests with the prototype.

During Phase II, a prototype system will be fabricated and tested. The model will be used to verify the applicability of the ice boring technique to the ADOM system. A series of test will be run during winter 1979. These tests will be used to obtain engineering data on the ice boring system. These data will be used to validate the prototype model and to solve operational problems which would affect Arctic testing of the system. Arctic field tests are expected to take place during 1979.

The program designed as Phase II and built around the above objectives is perceived to have 4 major tasks as follows:

A. Define initial design concepts (specific task statements)

1. Hot point system

   a. Thermodynamic analysis

      i. hot point/heater/water/ice

      ii. scrubbing system

   b. Computer model for hot point system

2. Energy and control system

   a. Battery system

      i. actual energy density for ADOM

      ii. actual current capacity

      iii. corrosion problems

      iv. efficiency of batteries at design temperatures and configurations

3. Mechanical integration of ice drill system components

   a. Erection and initial start up

   b. Total ADOM system integration considerations

B. Develop prototype system design

1. Test computer model with empirical data.

2. By means of computer simulation, adjust variables (e.g. speed, flow rate, size, energy density, etc.)

3. Develop an initial prototype system design and review this design

4. Develop an improved and final design for a prototype system to be used for testing

C. Fabrication of prototype system

1. Drawings (fabrication and assembly)

2. Documentation

3. Fabrication

D. Testing

1. Develop an overall test program for the prototype system to include test facilities fabrication, lab tests of specific components, prototype system lab tests, and finally a comprehensive prototype operational test program at CRREL or an equivalent facility

Phase II Plan Development

In the original statement of the Concept Development Plan (Appendix 1) a choice was contemplated between the four systems that were named. The study, however, succeeded in generating 87 systems and their variants, a fact that diverted the program substantially and lead to the as yet uncompleted Heat Transfer Analysis reported in Section 5. The consequences of this analysis do have a substantial bearing on the Phase II design details. It is anticipated that the Phase II program must be more fully defined at the conclusion of that work, scheduled for late November 1978. A more complete plan will be issued at that time.

APPENDIX 1: TASK DESCRIPTIONS ESTABLISHED AT PROGRAM START

PHASE I - CONCEPT DEFINITION PHASE

The concept definition phase of this proposed study will focus on two basic objectives:

1. Establishing a sound technical basis for penetrating the ice-covered oceans. The concepts and systems developed will be consistent with the ADOM concept as outlined in the ONR Progress Report of August 1977.
2. Contributing Arctic engineering concepts and technologies to the ADOM team.

A concept definition study is proposed consisting of the following elements:

1. Assessment of Arctic technologies and data bases
2. Examination of ice penetration system concepts
3. Analysis of system characteristics and trade off studies of ice penetration concepts
4. Development of a preferred design concept for ice penetration
5. Recommendations for a concept validation phase

These five elements are discussed below.

1. Assessment of Arctic Technologies and Data Bases

Many workers have considered the problems of ice drilling in polar regions; principal among these are the U. S. Army Cold Regions Research and Engineering Laboratory (CRREL), the Canadian Polar Shelf Study, and the extensive studies of the Russians and Japanese. The full extent of this technology will be gathered, assimilated and abstracted. Assumptions made earlier in the ADOM Program will be verified. A full assessment of applicable Arctic technologies and data bases will be

made and related to the ADOM Program as outlined in Reference 1.

2. <u>Examination of Ice Penetrator System Concepts</u>

Detailed examination will be made of the four drilling systems that are currently believed to show some potential for unmanned applications. These are:

A. Electro-thermal, whereby a battery driven resistive element heats the ice, lowering the instruments, while leaving the main system package on the ice surface.

B. Chemo-thermal drilling, where the energy source is a chemical, releasing heat on command or on contact with the ice.

C. Impact penetrometers, creating a hole through the impact of an air dropped element, with the remainder of the system probably landing by a tethered parachute to reduce deceleration forces.

D. Mechanical augers. Here unmanned adaptations of existing technology is contemplated.

In the Appendix, these concepts are briefly developed, and useful references in the literature are noted. Perceptions of scientists, familiar with the technologies, are also noted.

The potential for systems that avoid drilling by employing open water deployment in leads will also be examined. A reevaluation will be made of the available ice-thickness histogram and of ice characteristics as they relate to the needs of this project.

Alternative drilling systems will be sought out to broaden the list. The study will further review and recommend candidate aircraft for deployment in polar regions.

3. Analysis of System Characteristics and Trade-Off Studies of Ice Penetration Concepts

A detailed analysis will be made to establish specific characteristics of each system concept. These system parameters then will be compared to determine an optimum system concept.

System characteristics which will be included in the studies and tradeoff analysis are:

- energy requirements
- size
- weight
- applicability of available technology
- portability/ease of air deployment
- failure modes
- reliability and survivability
- Arctic environment compatibility
- cost
- prototype fabrication time
- compatibility with existing ADOM components

The outcome of this aspect of the study is conceived to be a thorough understanding of the current state of the art of ice penetration and related technologies and their potential to the ADOM Program.

4. Development of Design Concept for Ice Penetration

Having determined specific optimum parameters, a design concept will be developed. An initial system design will be made in sufficient detail to support a concept validation model and to permit reassessment of the time schedule as well as the development costs involved in the prototype system fabrication and testing.

5. Recommendation for a Concept Validation Phase

Phase I will terminate with a distribution of all background data to the ADOM Committee, a full technical presentation to the committee and a thorough analysis and review of the design. Due to time limita-

tions which exist in the ADOM schedule, the design concept which will be selected for fabrication of a prototype system must have the maximum probability of success. An effort will be made, throughout Phase I, to inform the ADOM Committee of pertinent design implications as they evolve. In this manner, it will be possible to recognize potential problem areas which might interfer with other components of the ADOM system. A recommendation for one design concept for ice penetration and for undertaking a validation study will be made by July 1, 1978. It is expected that the ADOM Committee will meet during July to consider this design concept and to establish, in consultation with ONR, the framework for the Phase II effort.

PHASE II - CONCEPT VALIDATION PHASE

The outcome of the Phase I effort will be a definitive recommendation for a system to penetrate the ice-covered ocean in a manner consistent with the ADOM Program objectives. Following approval of a Phase II program by the ADOM Committee and ONR, an effort to design, develop and test a prototype of the ice penetration system will be started. The purpose of Phase II is:

> To conduct detailed technical studies of the recommended penetration concept, to design and develop a working prototype of the penetration system (devoid of air deployment hardware, electronics and sensors but compatible with the other components of ADOM) and to conduct preliminary tests with the prototype.

During Phase II, a prototype system will be fabricated and tested. The model will be used to verify the applicability of the ice boring technique to the ADOM system. A series of tests will be run during February 1979 at the UNH Field Station at Lake Winnipesaukee. These tests will be used to obtain engineering data on the ice boring system. These data will be used to validate the prototype model and to solve operational problems which would affect Arctic testing of the system. Arctic field tests are expected to take place in the April to May period of 1979.

APPENDIX 2: References

1. A. C. Electronics-Defense Research Laboratories, Proposal For a Program to Demonstrate Feasibility of a Pyrotechnic Ice Penetrator, 1969.

2. Aamot, H. W. C., Pendulum steering for thermal probes in glaciers, U.S. C.R.R.E.L. Technical Report 116, 1967a.

3. Aamot, H. W. C., Heat transfer and performance analysis of a thermal probe for glaciers, U.S. C.R.R.E.L. Technical Report 194, 1967b.

4. Aamot, H. W. C., The Philberth probe for investigating polar ice caps, U.S. C.R.R.E.L. Special Report 119, 1967c.

5. Aamot, H. W. C., "Instrumented probes for deep glacial investigations," Journal of Glaciology, 1968a, Vol. 7, pp. 321-328.

6. Aamot, H. W. C., "A buoyance-stabilized hot-point for glacier studies," Journal of Glaciology, 1968b, Vol. 7, pp. 493-498.

7. Aamot, H. W. C., Winding long, slender coils by the orthocyclic method, U.S. C.R.R.E.L. Special Report 128, 1969.

8. Aamot, H. W. C., "Development of a vertically stabilized thermal probe for studies in and below ice sheets," Journal of Engineering for Industry, 1970a, pp. 263-268.

9. Aamot, H. W. C., "Self-contained thermal probes for remote measurements within an ice sheet," International Symposium on Antarctic Glaciological Exploration (ISAGE), Hanover, NH, September 1968, 1970b, IASH Publication No. 86, pp. 63-68.

10. Ackley, S. F., Hibler, W. D. III, Kovacs, A., Weeks, W. F., Hartwell, A., and Campbell, W. J., Investigations performed on the Arctic ice dynamics joint experiment - March 1971, U.S. C.R.R.E.L. Research Report 315, 1973.

11. Ackley, S. F., Hibler, W. D. III, Kugzruk, F. K., Kovacs, A., and Weeks, W. F., Thickness and roughness variations of Arctic multiyear sea ice, U.S. C.R.R.E.L. Report 76-18, 1976.

12. Argos, ADOM satellites, 1977.

13. Bajzak, D., and Langford, C. J., "Sea ice mapping of the Labrador pack from satellite imagery," XXI Rassegna Internazionale Elettronica E Mucleare, 1974, pp. 377-386.

14. Barnes, J. C., Bowley, C. J., Smallwood, M. D., and Willand, J. H., "Use of satellite data to evaluate surface ice conditions for off-shore oil and gas exploration," POAC 77, 1977, Vol. II, pp. 1019.

15. Benert, R., Penetration of shaped-charges into frozen ground, U.S. C.R.R.E.L. Report TR 45, 1977.

16. Black, S. A., and Sergev, S. S., A self-contained experimental diver heater (Port Hueneme, CA: Naval Civil Engineering Laboratory) 1977a.

17. Black, S. A., and Sergev, S. S., Development and Evaluation of Supercorroding Alloys (Port Hueneme, CA: Naval Civil Engineering Laboratory) 1977b.

18. Black, S. A., and Sergev, S. S., Supercorroding Alloys for Generating Heat and Hydrogen Gas (Port Hueneme, CA: Naval Civil Engineering Laboratory).

19. Black, S. A., Tucker, L. W., Vind, H. P., and Hitchcock, R. D., Preliminary Development of an Electrochemical Heat Source for Military Diver Heating (Port Hueneme, CA: Naval Civil Engineering Laboratory) 1973.

20. Brown, W. P., and Kerut, E. G., Air Droppable RAMS (ADRAMS) Buoy (Santa Barbara, CA: Polar Research Laboratory).

21. Browning, J. A., Flame jet gains ground as blasthole drill, Engineering and Mining Journal, 1969.

22. Browning, J. A., Discussion and Recommendations on Air-Deployed Oceanographic Mooring in Arctic Ice Pack (Hanover, NH: Browning Engineering Corp.) 1978a.

23. Browning, J. A., Alternative Methods for Hot Water Drilling in Arctic Pack Ice: A Report and Preliminary Proposal (Hanover, NH: Browning Engineering Corp.) 1978b.

24. Browning, J. A., and Somerville, D. A., Access Hole Drilling Through the Ross Ice Shelf (Hanover, NH: Browning Engineering Corp.)

25. Colp, J. L., Ed., Rapid Penetration of Terrestrial Materials: Proceedings of a Conference Held at Texas A&M University on February 1-3, 1972.

26. Francois, R. E., and Harrison, J. G., Thermal drill for making large holes in sea ice, IEEE Ocean '75, 1975.

27. Frankenstein, G., Ice Engineering Program: First Annual Report (Hanover, NH: C.R.R.E.L.) 1976.

28. Frankenstein, G. E., and Abrams, W. R., Acoustic Reflection Measurements of Sea Ice Thickness, Barrow, Alaska (Hanover, NH: C.R.R.E.L., and Portsmouth, NH: Raytheon Corp.)

29. Groft, E. G., and Faeth, G. M., "Steady metal combustor as a closed thermal energy source," Journal of Hydronautics, 1978, Vol. 12, pp. 63-70.

30. Hibler, W. D., Weeks, W. F., and Mock, S. J., Statistical aspects of sea-ice ridge distribution, U.S. C.R.R.E.L.

31. Hodge, S. M., "A new version of the steam-operated drill," Journal of Glaciology, 1971, Vol. 10, pp. 387-393.

32. Howorka, F., "A steam-operated drill for the installation of ablation stakes on glaciers," Journal of Glaciology, 1965, pp. 749-750.

33. Jones, J. M., The design of a large shaped charge suitable for the perforation of Arctic sea-ice (Quebec, Canada: Defense Research Establishment Valcartier) 1970.

34. Koerner, R. M., "Weather and ice observations of the British trans-Arctic expedition 1968-9," Weather, 1970, Vol. 25, pp. 218-228.

35. Koerner, R. M., "The mass balance of the sea ice of the Arctic Ocean," Journal of Glaciology, 1973, Vol. 12, pp. 173-185.

36. Kovacs, A., "Iceberg profiling thickness," POAC 77, 1977, Vol. II, pp. 766.

37. Kovacs, A., Weeks, W. F., Ackley, S., and Hibler, W. D., "A study of a multiyear pressure ridge in the Beaufort Sea," AIDJEX Bulletin No. 12, February 1972.

38. Kudriashov, R. B., and Fisenko, V. F., Thermal Drilling of Snow-Form and Ice in Antarctica, 1973.

39. Langleben, M. P., and Pounder, E. R., Sea Ice Thickness from Pulsed Sonic Methods (Montreal, Canada: McGill University)

40. LeSchack, L., Probability of Finding Thin Ice for ADOM Deployment, 1977.

41. McIntosh, J. A., Young, C. W., and Welsh, J. P., Sea Ice Penetrometer Development, 1972.

42. McLeod, W. R., and Hodder, D. T., "An examination of long term ice forecast and periodicities of the Beaufort Sea," POAC 77, 1977, Vol. II, pp. 1035.

43. Marko, J., Satellite Observations of the Beaufort Sea Ice Cover - Beaufort Sea Technical Report #34, 1975.

44. Mellor, M., Explosive Blasting in frozen ground, U.S. C.R.R.E.L. Report SR 153, 1970.

45. Mellor, M., Relationships for jet cutting, U.S. C.R.R.E.L. Report MP 319, 1972.

46. Morev, V. A., Efficiency and Economics of Electrothermal Devices during Inland Ice Drilling, 1972.

47. Morev, V. A., and Shamont'yev, V. A., Experimental Ice Drilling.

48. Muggeridge, D. B., Ed., POAC Proceedings, Volumes I and II (St. John's, Newfoundland, Canada: Memorial University of Newfoundland) 1978.

49. Naval Ordnance Laboratory, Arctic Sonobuoy Development, 1969 (U) (Santa Barbara, CA: A C Electronics-Defense Research Laboratories) 1970.

50. Parsons, R. C. and Hopkins, R. M., "A chemical method for ice destruction," POAC 77, 1977, Vol. II, pp. 799.

51. Pounder, E. R., Langleben, M. P., and Becker, A., A Seismic Method for Average Ice Thickness (Montreal, Canada: McGill University).

52. Ramseier, R. O., Vant, M. R., Arsenault, L. D., Gray, L., Gray, R. B., and Chudobiak, W. J., Distribution of Sea Ice Thickness in the Beaufort Sea - Beaufort Sea Technical Report #30, 1975.

53. Rogers, J. C., "A meteorological basis for long-range forecasting of summer and early autumn sea ice conditions in the Beaufort Sea," POAC 77, 1977, Vol. II, pp. 952.

54. Ross, B., Hanagud, S., and Sidhu, G., Penetration Studies of Ice with application to Arctic and Subarctic Warfare (Menlo Park, CA: Stanford Research Institute) 1971.

55. Rossiter, J. R., Langhorne, P., Ridings, T., and Allan, A. J., "Study of sea ice using impulse radar," POAC 77, 1977, Vol. I, pp. 556.

56. Saar, R., "Ammonia-Ice Drilling System;" personal communication (Dept. of Chemistry, U.N.H.) 1978.

57. Sanders Nuclear Corp., Heat stick ice melter for deployment of payloads through Arctic ice (Nashua, NH: Sanders Nuclear Corp.) 1970.

58. Shreve, R. L., "Theory of performance of isothermal solid-nose hotpoints boring in temperate ice," Journal of Glaciology, 1962, Vol. 4, pp. 234-235.

59. Shreve, R. L., and Sharp, R. P., "Internal deformation and thermal anomalies in Lower Blie Glacier, Mount Olympus, Washington, U.S.A.," Journal of Glaciology, 1970, Vol. 9, pp. 65-86.

60. Splettstoesser, J. F., Ed., Ice-Core Drilling: Proceedings of a Symposium, University of Nebraska, Lincoln, 28-30 August, 1974 (Lincoln, Nebraska: University of Nebraska Press) 1976.

61. Swanson, J. C., Feasibility and Costs of Candidate Power Sources for Arctic Operations (Office of Naval Research, Arctic Program, Code 461) 1976.

62. Swithinbank, C. (See reference #74)

63. Thorndike, A. S., Rothrock, D. A., Maykut, G. A., and Colony, R., "The thickness distribution of sea ice," Journal of Geophysical Research, 1975, Vol. 80, pp. 4501-4513.

64. Tien, C., Preliminary calculations of the energy requirement for placing an instrument package under ice, U.S. C.R.R.E.L. Research Report 146, 1965.

65. Tien, C., Energy requirements for melting through ice cover, U.S. C.R.R.E.L. Report RR 146.

66. Ueda, H. T., Drill for thermal coring in ice, U.S. C.R.R.E.L. Report MP 445, 1968.

67. Ueda, H. T., and Garfield, D. E., Drilling through the Greenland ice sheet, U.S. C.R.R.E.L. Special Report 126, 1968.

68. Ueda, H. T. and Garfield, D. E., Core drilling through the Antarctic ice sheet, U.S. C.R.R.E.L. Technical Report 213.

69. Ueda, H. T., and Garfield, D. E., "The USA CRREL drill for thermal coring in ice," Journal of Glaciology, 1969, Vol. 8, pp. 311-314.

70. Wadhams, P., A comparison of sonar and laser profiles along corresponding tracks in the Arctic Ocean.

71. Wadhams, P., Sea Ice Morphology in the Beaufort Sea - Beaufort Sea Technical Report #36 (Victoria, B. C.: Dept. of the Environment) 1975.

72. Wadhams, P., "Characteristics of deep pressure ridges in the Arctic Ocean," POAC 77, 1977, Vol. I, pp. 544.

73. Warburton, J. A., Schwalenberg, E., and Kleppe, J. A., "The use of an X-band radar and satellite communications link for studies of air-sea interactions on the Antarctic penisula," POAC 77, 1977, Vol. II, pp. 1064.

74. Williams, E., Swithinbank, C., and Robin, G., "A submarine sonar study of Arctic pack ice," Journal of Glaciology, 1975, Vol. 15, pp. 349-362.

75. Worsfold, R. D., Strong, D., and Wedler, E., "Project SAR 77," POAC 77, 1977, Vol. II, pp. 1051.

76. Young, C. W., A Parametric Study of an Ice Penetrating Sonobuoy Vehicle, (Albuquerque, NM: Sandia Laboratories), 1972a.

77. Young, C. W., Empirical Equations for Predicting Performance in Layered Earth Materials for Complex Penetrator Configurations (Albuquerque, NM: Sandia Laboratories), 1972b.

78. Young, C. W., Sea Ice Penetration (Albuquerque, NM: Sandia Laboratories)

79. Young, C. W., and Kiker, L. J., An Air Dropped Sea Ice Penetrometer, Report SC-DR-70-483 (Albuquerque, NM: Sandia Laboratories), 1970.

80. Zotikov, I. A., Thermal Drilling into Ice Sheets, 1972.

81. Zotikov, Kapitsa, Kudryavtsev, and Sukhanov, Thermal drilling of the glacier, U.S. C.R.R.E.L. Report TL-414, 1974

APPENDIX 3

DISCUSSION AND RECOMMENDATIONS ON AIR-DEPLOYED OCEANOGRAPHIC MOORING IN ARCTIC ICE PACK

By:

James A. Browning
BROWNING ENGINEERING CORPORATION
P.O. Box 863, Hanover
New Hampshire 03755

Submitted to:

UNIVERSITY OF NEW HAMPSHIRE
Durham, New Hampshire 03824

Attention: Dr. Robert W. Corell
Marine Program
Kingsbury Hall

May 19, 1978

DISCUSSION AND RECOMMENDATIONS ON AIR-DEPLOYED OCEANOGRAPHIC MOORING IN ARCTIC ICE PACK

ABSTRACT

An evaluation of several different methods for piercing a 6-inch diameter hole through up to 40 feet of arctic ice pack has been made. Limitations imposed by factors including automatic positioning and operation following an air-drop would appear to require the simplest possible approach.

The most promising method utilizes a hot water drill requiring a water supply at an initial temperature of 200°F. Assuming a 100°F temperature drop (while jet-drilling) an average drilling speed of 6 Ft/Min should be attainable at a flow rate of 15 gpm. Minimum drilling time for the thickest ice (40 feet) is about 7 minutes. The theoretical amount of water required is 105 gallons. At least double this amount should be provided to allow for non-design conditions.

The hot water, carried in a portion of the air-dropped cannister, is pressurized to a fixed value by a tank of high-pressure air and regulator. This water is forced to flow (after a fixed delay after landing) from the cannister through a hose connected to the 400-pound probe (later to become the anchor). The delay is required to allow time for the probe to align itself nearly vertically from a possible horizontal position upon landing. The probe, perhaps made of lead, would be pre-heated prior to the air drop.

DISCUSSION

A rather cursory analysis of both "passive" and "active" ice pack drills has been made. The drilling methods are obvious ones. Others, not covered in this report, must exist and should be considered as viable alternatives.

Passive probes include:

(1) Solid mass of a single material heated to high temperature.
(2)- a. Material of high heat-of-fusion contained in a hollow probe.
- b. Material of high heat-of-vaporization contained in a hollow probe.

(3) Container heated by chemical reaction within - Thermit.
(4) Probe heated by an outside source
    a. Electrical
    b. Combustion
    c. Hot water

Active probes include:

(5) Flame jet
(6) Water jet
    a. Below boiling temperature
    b. Above boiling temperature - Hot water "rocket"

Prior to discussing these individual items it is necessary to know the heat requirements for producing a 6-inch diameter hole in ice 40 feet thick. The cross-sectional area of the hole is 0.196 Ft^2 with a volume of 7.86 Ft^3. At an ice density of 0.9 that of water, it is necessary to melt nearly 445 pounds of it. Each pound of ice requires about 150 Btu heat input to be melted. Total heat flow is 66,750 Btu.

(1) A 400-pound probe of solid steel heated to 1,800°F with a specific heat of about 0.1 Btu/lb/°F would release nearly 68,000 Btu while cooling to 100°F. It would be nearly impossible to use this to drill a 6-inch hole. A 6-inch diameter steel probe would be over 4 feet long. Even if it were to align vertically in the ice during its descent, the hole diameter would be much greater than 6 inches due to heat release over its entire length. More heat requires a larger mass. It is a "circular" path to nowhere. Other metals would not improve the situation significantly, except for beryllium, or the like.

(2)- a. Filling a hollow probe of metal with a material of high heat content appears more favorable. Assume a 200-pound steel

container holding 200 pounds of molten aluminum. The total heat release capability increases to 140,000 Btu. The problem -- the the aluminum weighs so little that the probe would have to be much bigger. Also, the unit is much more complex and expensive.

(2)- b. The same sort of argument may be used against the hollow probe containing a substance of high heat-of-vaporization. The 400-pound anchor weight requirement is severe.

(3) By substituting a chemical reaction for the above filler materials leads to a much increased heat release capability. About 600,000 Btu could be made available using Thermit. But, the problems are immense. The speed of reaction would have to be slowed to match the drilling speed. The ignition temperature requirement of 2,200°F means another component must be included. The reaction progresses at up to 5,500°F presenting serious overheating problems to the container. Slower reaction rates using inert filler material and refractory coatings of the inner container wall should not be over-looked. Certainly, this is the most worthwhile of the passive probe designs.

(4) This last category provides a simple probe heated by an outside source such as a battery, combustion device, or supply of hot water. Again, penetration rates would be slow -- hole diameter large.

The major disadvantage of the passive system is its inability to match the heat "acceptance" rate of the ice. Active scouring-away

of the boundary layer leads to an order-of-magnitude higher drilling speed. This is dramatically illustrated in the current practice of using an electrically-heated probe of 1-foot diameter to melt deep holes into the ice below glacial firn. At Antarctica, Lyle Hansen used such a device very successfully to establish a large water well access hole during the 1977 season.* At an electric heat input rate of 4½ KW, a drilling rate of 1 meter per hour was achieved. This is the equivalent heat content of a hot water jet of only ¼ gpm.

(5) A flame jet of 3,300°F issuing from an internal burner consuming 600 scfm of compressed air (18 gph of fuel oil) at 300 psig drills a 12-inch hole in ice at nearly 6 Ft/Min. But, the system is extremely complex -- thus, the most unreliable of all the options for an air drop. Such systems are to be avoided, including those powered by pure oxygen.

(6) Finally, the system offerring a sufficient amount of heat in a package simple enough to do the job at reasonable cost is the hot water jet. Such a jet can be pressurized by an external source such as a small tank of compressed gas, or by heating the water to a temperature well above its atmospheric pressure saturation level. The latter case presents a trade-off of added heating capability of the "hot water rocket" against its more

* Verbal Communication from Mr. Hansen, UNIVERSITY OF NEBRASKA.

complex container requirements due to its much higher pressure.

A larger amount of hot water (below its boiling point) appears more favorable for producing the required heat than the "rocket". A preliminary analysis, based on the heat requirement of 67,000 Btu, shows a minimum water requirement of 84 gallons. This assumes an initial temperature of 200°F and a T= 100°F during drilling. (With a specific heat of 1 Btu/lb/°F, 670 pounds of water are needed -- 84 gallons.) Using a flow of 15 gpm a 6-inch hole could be made at nearly 6 Ft/Min. For a 40-foot ice thickness, the penetration time would be 7 minutes. A minimum of 200 gallons should, probably, be provided.

The system to be dropped (*not including* the scientific package, radio, etc.) consists of a water tank which can be an integral part of the cannister, means to pressurize this tank, a hose from the tank to the probe, and the 400-pound probe. Figure 1 is a sketch showing these elements after a successful drop. (A successful drop may be defined as one where the components are neither tangled together or damaged beyond use. It does include the probe lying horizontally, as shown.)

Assuming a 200-gallon tank, its volume is about 26 Ft^3. A high-pressure tank of compressed air, for pressurizing this tank to, say, a constant 200 psig, would have to have a volume of nearly 3 Ft^3 for an initial pressure of 2,000 psig. A regulator would provide the constant pressure flow.

The size of the probe remains a problem. Assuming a 6-inch diameter hole requirement, the probe must have a diameter somewhat less -- select 5 inches. A steel cylindrical probe would be nearly 6 feet long. Lead would be a more logical choice. It would be less than 2 feet long. The shorter cylinder is more adaptable for the design of an automatic technique for raising itself into the near-vertical position as it melts its way into the ice.

Our idea is to heat the probe to as a temperature as practical. Assuming the horizontal position of Figure 1, the probe will sink into the ice as shown by the dotted lines. The nose portion of the probe presents an exposed heated surface to the ice. The remainder is covered by an insulating layer. The stabilizer further assists in the vertical alignment.

After a "known" period of time, the probe will have righted itself. At this moment (or by a signal from a level-sensing mercury switch) the water flow would be turned "on".

The overall hot water jet system is simple, reliable, and inexpensive. Of the alternatives I have investigated it appears the most suitable. The second best alternative is a choice between the "hot water rocket" or the Thermit system. A combination of Thermit heating of the probe followed by hot water drilling is also attractive.

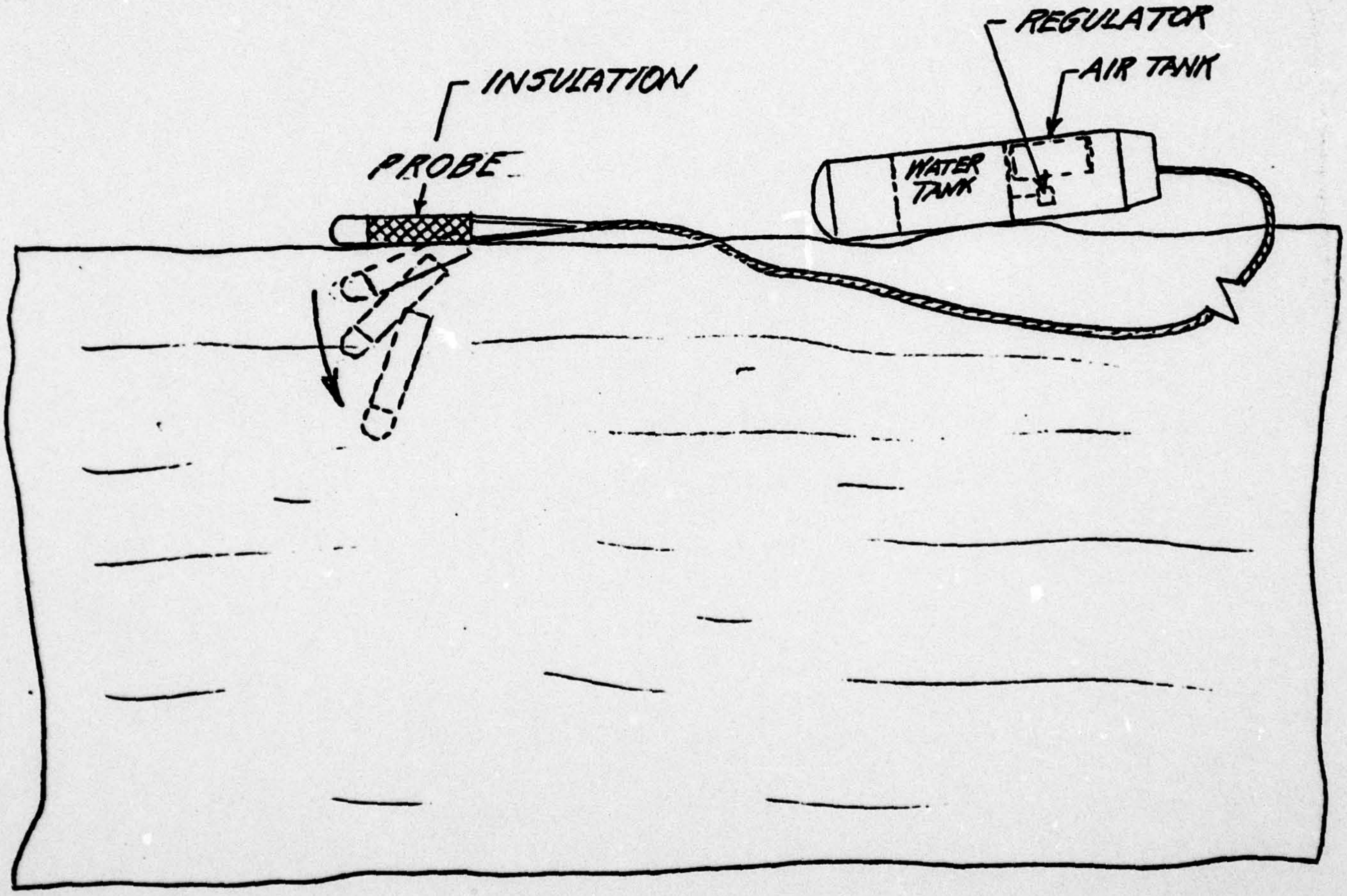


FIGURE 1 -- Schematic of hot water drill system with heated probe shown seeking vertical position.

APPENDIX 4

AN OVERVIEW OF A SUPER-CORRODING ALLOY DRILL

A family of super-corroding iron-magnesium alloys (hereafter called "SCIM" for ease of reference) that react spontaneously and in a controllable fashion with sea water to produce heat and hydrogen gas has been developed by the Civil Engineering Laboratory in Port Hueneme, California. The super-corroding alloys are formed by mechanically bonding anodic metals (magnesium) to cathodic materials (iron, copper, nickel). The reaction rates can be controlled by the cathodic material and its percentage content, and by controlling temperature, pressure and salinity.

This alloy is an attractive energy source because of its relatively high specific energy level, as the table below indicates.

Hydrocarbons	19,000 - 24,000 BTU/lb.	(5-6)*
"SCIM"	5,000 BTU/lb.	(25)
Lithium Batteries	430 BTU/lb.	(280)
Lead Acid Batteries	48 BTU/lb.	(2500)

Several concepts were considered using the -

1. Ablative drill rod of "SCIM" (wherein the rod heats and "melts" away while drilling, with a controlled flow of water to the drill tip.
2. A reaction chamber, either in drill head or on ice surface, producing the required heat which is transferred by a flow of water to the drill head.

*Wt. of "fuel" required, with 100% efficiency, to drill 6" diameter hole, 50 feet deep in ice.

Analysis was conducted for each of these two generic categories for three drill sizes (2", 4" and 6") and for three drilling rates 50 feet/hr., 8 feet/hr., and 4.5 feet/hr. (other drill rates are possible, both faster and slower).

The total energy required (assuming 100% efficiency) to drill 15 meters (50 feet) in Kw-hr is:

Drill Dia.	50 feet/hr.	8 feet/hr.	4.5 feet/hr.
2"	7.5 Kw-hr.	13 Kw-hr.	17 Kw-hr.
4"	15 Kw-hr.	26 Kw-hr.	34 Kw-hr.
6"	34 Kw-hr.	47 Kw-hr.	60 Kw-hr.

These energy requirements (100% efficiency) necessitate the following fuel packages:

Drill Dia.*	50 feet/hr.**	8 feet/hr.**	4.5 feet/hr.**
2"	2.1 ft./5.1 lb.	3.7 ft./91b.	4.8 ft./11.6 lb.
4"	1.1 ft./10.3 lb.	1.9 ft./18.1 lb.	2.4 ft./23.3 lb.
6"	1.1 ft./23.3 lb.	1.5 ft./23.3 lb.	1.9 ft./41.3 lb.

The reaction rates were designed to operate at about 4°C, although much higher rates of heat production is possible at higher temperatures (Ranging from 30 watts/gram at 4°C to 180 watts/gram at 60°C as the average power production).

---

*This is the diameter of the rod.

**This is the length of the rod and its weight.

ABLATIVE APPROACH

The question that must be answered is: Can the required power be produced at the required rate in a region where the catalytic reaction can occur? The process occurs with a mass of foam and H_2 bubbles being generated. For example, to produce 8 Kw of power, 266 grams of "SCIM" must be kept "wet" with "clean" sea water. These 266 grams will last 6-7 minutes, thus 45 grams of "SCIM" must be wetted every minute to produce 8000 watts of power. Doing this calculation indicates that the bottom 1.5 to 3 inches of the rods must be kept wet for the 2, 4, and 6 inch drill diameter. In short, it is possible to concentrate the heat production in the bottom 1.5 to 3 inches of the rods, so it acts like a "point source" of heat. The H_2 produced may create a stirring action, that may act like scrubbing.

The heat transfer calculations, while designed for the heated hot tip approach, suggest that an ablative drill has potential. Questions exist, however, on the necessary approaches to achieve the best release.

REACTING CHAMBER APPROACH

Several design concepts were considered, each, however, did not overcome the problem that CEL has had with chamber reacting systems. All chamber reacting concepts involve a reacting slurry, a semi-closed or a closed reacting chamber. In all cases, the reaction is seriously inhibited by foaming of the products of the reaction. The result is a substantial reduction in efficiency of heat production. The open system concept with an ablative "SCIM" rod probably can be designed to overcome this problem.

AD-A068 436 NEW HAMPSHIRE UNIV DURHAM MARINE SYSTEMS ENGINEERING LAB F/G 8/10
AIR DEPLOYED OCEANOGRAPHIC MOORING (ADOM).(U)
FEB 79 N00014-78-C-0335

UNCLASSIFIED NL

2 OF 2
ADA
068436

END
DATE
FILMED
6 79
DDC

There are opportunities and problems with this approach.

Assets in the Approach

1. Energy density is relatively high.
2. SCIM fuel requirements are with ADOM specifications.
3. Catalytic recombination of H_2 produced with O_2 can just about double the energy density.
4. It looks like a package can be designed.

Limitations

1. The numbers used for the preliminary design calculations must be verified by actual cold environment experiments. While probably valid to within 25-50%, they must be validated.
2. Prototype experiments with "fuel" rods will have to be conducted to increase the probability of achieving an operating system. Too many unknowns that can't be fully evaluated by theoretical predictions, i.e. effect of gasing on heat transfer, exist.
3. Several other systems questions remain unanswered, such as how do you initiate the reaction, which may require initial electrical heating, and how do you supply the salt to the reaction site?

These assets and limitations, when combined, suggest to us that the super-corroding iron-magnesium (SCIM) alloy has the potential of meeting Arctic/ADOM requirements provided an R&D program is undertaken to answer the several critical questions outlined above.

REFERENCES

1. Civil Engineering Laboratory. Technical Note N-1315, "Preliminary Development of an Electrochemical Heat Source for Military Diver Heating;" by S. A. Black et al., November 1973.

2. Patent Application, "High Corrosion Rate Alloys," Navy Case No. 61,029, 15 June 1976, by S. A. Black, Sergev, S.S. and Jenkins, J.

3. Black, S. A. and S.S. Sergev, "Development of a Self-Contained Heater for Military Divers," OCEANS '75, pp. 258 - 262.

4. Benjamin, J. S., "Mechanical Alloying," Scientific American, May 1976, Vol. 234, No. 5, pp. 40 - 48.

5. Civil Engineering Laboratory. Technical Note N-1501, "A Self-Contained Experimental Diver Heater," by S. A. Black and Sergev, S. S., September 1977.

6. U.S. Navy Patent, No. 3,942,511, "Sandwiched Structure for Production of Heat and Hydrogen Gas," S. A. Black, et al., March 9, 1976.

7. U.S. Navy Patent, No. 3,993,577, "Method for Production of Heat and Hydrogen Gas." S. A. Black et al., November 23, 1976.

8. U.S. Navy Patent, No. 4,017,414, "Powdered Metal Source for Production of Heat and Hydrogen Gas," S. A. Black et. al., April 12, 1977.

9. Naval Weapons Center, Technical Paper 4953, "A Study of Gas Generators for Ship Salvage Buoyancy Systems," by J. Bryant, June 1970.

APPENDIX 5

"Ice-Core Drilling"

INTRODUCTION

Mechanical Penetration

Mechanical penetration has been accomplished by rotating a cutting bit, impacting with a chopping bit (cable drilling), vibratory driving of the drill pipe and ballistic impact. For the first two means the motive power may be either a human being or an engine.

Rotary drilling and coring in temperate ice has been accomplished, removing the cuttings by augering or circulating water. For cable drilling at least part of the hole is filled with water to flush the cuttings from the chopping bit and hole bottom. The cuttings are removed by a bailer.

Rotary drilling and coring in cold ice has been accomplished, removing the cuttings by augering, circulating a fluid (either air or a non-freezing liquid), and dissolving the cuttings in aqueous ethylene glycol. Ragle *et al.* (1964) used a SIPRE 3-in. coring auger to core drill to a depth of 55 m on the Ward Hunt Ice Shelf in 1960. This is surely a record depth for man-powered core drilling in ice. The 2164-m-deep hole through the Antarctic Ice Sheet at Byrd Station by the CRREL drill team in January 1968 is the deepest hole drilled in ice to date.

Vibratory drilling and coring in cold ice to depths of tens of meters has been accomplished. With this type of penetration and with the ballistic impact the ice flows away from the penetrator and there are no cuttings to remove.

For those who want to delve into the history of drilling and coring in ice several summaries have been written. The most recent one, by Langway (1970, p. 6 and 146-148), is a small portion of a larger work. Langway's paper has an extensive bibliography citing most of the references pertinent to the history of core drilling in ice from 1949 to 1969. Miller (1952-1953) has covered thermal drilling prior to 1953, and also mechanical drilling in ice prior to 1950 (Miller, 1954).

REFERENCES

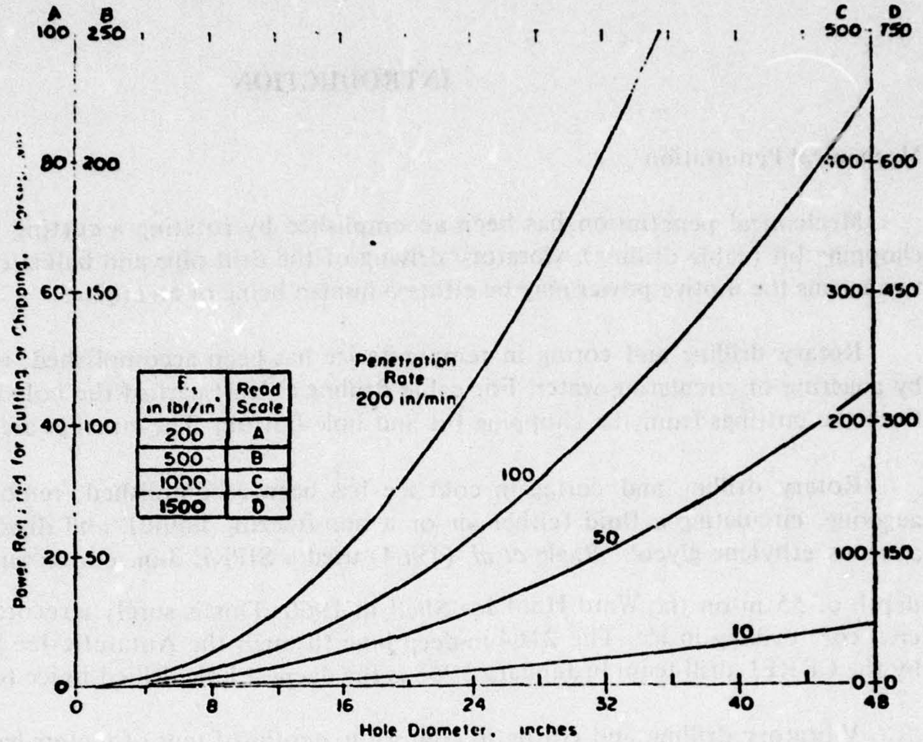
Langway, Chester C. Jr., 1970. Stratigraphic analysis of a deep ice core from Greenland: Geological Society of America Special Paper 125, 186 p.

Miller, M.M., 1952-1953, The application of electro-thermic boring methods to englacial research with special reference to the Juneau Icefield investigation in 1952-53: Arctic Institute of North America Report No. 4, Project ONR-86.

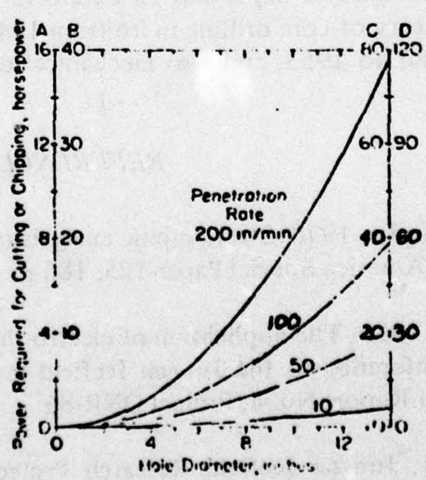
Miller, M.M., 1954, Juneau Icefield Research Project, Alaska, 1950: American Geographical Society, JIRP Report No. 7.

Ragle, R.H., R.G. Blair and L.E. Persson, 1964, Ice core studies of Ward Hunt Ice Shelf, 1960: *Journal of Glaciology*, v. 5, no. 37, pp. 39-59.

B.L. Hansen



a.



b.

Basic power requirement for cutting or chipping shown for a range of hole diameters, penetration rates, and specific energy levels.

MEASURED PENETRATION RATES FOR EXISTING DRILLING TOOLS

The following notes give examples of actual penetration rates for various types of existing equipment. Most of the information is taken from an unpublished report by Mellor *et al.* (1973), which illustrates many of the pieces of equipment that are referred to.

Ice. Drilling in ice presents no great problem if the equipment is properly designed and operated, but some projects have foundered because of inability to drill ice. Well-designed drag bits are the simplest and probably the most efficient tools for cutting ice, as they require very little down-thrust, modest torque, and no percussion. If the ice is perfectly clean and of zero salinity, drag bits do not require carbide tips or hard-facing, although some surface hardening is desirable. A slight amount of rock dust can create wear problems (Abel, 1961), as can inclusions of precipitated salt crystals (G. Lange, unpublished).

Small-diameter holes can be drilled with simple hand equipment at rates that are acceptable for some purposes. The 1.5 in. (38 mm) diameter USA CRREL ice auger (essentially a ship auger with modified tip), rotated by a hand brace, can drill to 3 ft (1 m) at rates from 1.6 to 2.95 ft/min (8.1 to 15 mm/sec) (Kovacs, 1970; Sellmann and Mellor, 1974). With an electric or gasoline power-drive the same tool can penetrate to 3 ft (1 m) at rates from 3.2 to 7.6 ft/min (16 to 39mm/sec) (Kovacs, 1970; Kovacs *et al.*, 1973; Sellmann and Mellor, 1974). Like any auger, this tool can be overdriven so that cuttings jam in the flight, and care must be exercised to match penetration rate with cutting clearance rate.

A simple 1.5 in. (38 mm) diameter flight auger fitted with improved bits has drilled ice at rates up to 4.4 ft/min (22 mm/sec) when driven by a hand brace, and at rates up to 15.1 ft/min (77 mm/sec) when driven by electric hand drills (Sellmann and Mellor, 1974). A 2.2 in. (56 mm) diameter variant penetrated at rates up to 10.4 ft/min (53 mm/sec).

The USA CRREL 3 in. (76 mm) coring auger is sometimes used solely for drilling holes, producing a hole of approximately 4.4 in. (112 mm) diameter. When turned by a hand brace, penetration rates of 0.8 to 1.2 ft/min (4 to 6 mm/sec) have been measured; when the same tool was turned with a T-handle the rates dropped to 0.43 to 0.61 ft/min (2.2 to 3.1 mm/sec) (Kovacs, 1970). With a gasoline drive, rates of 3.0 to 3.5 ft/min (15 to 18 mm/sec) have been measured (Kovacs, 1970). With electric drive, penetration rate has been measured at 2.4 to 4.0 ft/min (12 to 20 mm/sec) (Kovacs, 1970) and 5.4 to 5.6 ft/min (27 to 28 mm/sec) (Kovacs *et al.*, 1973).

A Russian hand-operated cutting ring device, used for coring or hole making, produces an annular hole 8.8 in. (224 mm) O.D. and 7.25 in. (184 mm) I.D. at the rate of 0.2 to 0.33 ft/min (1 to 1.7 mm/sec) (Cherepanov, 1969). Drilling through 7 ft (2 m) thick first-year sea ice takes 30 to 45 min (R. Ramseier, personal communication).

A wide variety of commercial earth augers, or post-hole diggers, have been adapted for drilling ice, especially for the use of ice-fishermen. They commonly have diameters ranging from about 4 in. to 9 in. (0.1 to 0.23 m), and are normally intended for drilling to depths of only a few feet, although the writers have drilled to 16 ft (5 m) with 9 in. (0.23 m) diameter hand-held gasoline-powered augers. Kovacs (1970) has driven an 8 in. (0.2 m) diameter earth auger with various gasoline and electric drive units at a penetration rate of 1.2 ft/min (6.1 mm/sec). The writers have drilled numerous 9 in. (0.23 m) diameter holes at somewhat higher rates (approximately 3 ft/min) with freshly sharpened ice augers, and ice-fishermen have claimed rates approaching 5 ft/min (25 mm/sec) with 9 in. (0.23 m) diameter augers, and 6 ft/min (30 mm/sec) with 7 in. (0.18 m) diameter augers. In controlled tests, a 9 in. (0.23 m) diameter auger penetrated at 5.3 to 7.5 ft/min (27 to 38 mm/sec), and a 5.5 in. (0.14 m) diameter auger penetrated at 5.4 to 7.5 ft/min (27 to 38 mm/sec) (Kovacs *et al.*, 1973).

Shothole drills developed for underground mining have been used to drill ice with a minimum of modification. Rausch (1958) drilled 1.75 in. (44 mm) diameter shotholes in ice with pneumatic rotary-percussive mining drills, achieving penetration rates of 5 ft/min (25 mm/sec). Abel (1961) used percussive augers to drill 1.75 in. (44 mm) diameter shotholes, obtaining overall penetration rates better than 5 ft/min (25 mm/sec) for 8 ft (2.4 m) long holes. He also used a hand-held electric powered auger to drill 2 in. (51 mm) diameter holes at 5 ft/min (25 mm/sec). McAnerney (1968) used a hydraulically driven hand-held coal auger for boring 1.75 in. (44 mm) diameter shotholes in frozen silt and ice, obtaining penetration rates up to 11.75 ft/min (60 mm/sec) in lenses of pure ice. Kovacs *et al.* (1973) drove 1.75 in. (44 mm) diameter face augers and roof-bolt augers with electric drills, and achieved penetration rates up to 9.5 ft/min (48 mm/sec).

The writers have drilled with hand-held electrically driven 3 in. (76 mm) diameter augers to depths of 55 ft (17 m) using a variety of bits. With good bits, short-term penetration rates (4-ft increments) of 15 ft/min (76 mm/sec) were attainable. Controlled tests with similar tools gave penetration rates up to 14 ft/min (71 mm/sec) (Kovacs *et al.*, 1973). Kovacs (1974) has developed a lightweight 3 in. (76 mm) diameter auger that penetrates at up to 10.4 ft/min (53 mm/sec) with an electric drive unit. Similar rates of 3.4 to 13.9 ft/min (17 to 71 mm/sec) were reported for small-diameter auger drills in river and sea ice by Russian workers (Nikolaev and Trubina, 1969).

From the foregoing performance records it is clear that hand-held drive units are perfectly adequate for supplying the power, torque and thrust required for drilling holes up to 9 in. (0.23 m) diameter at fully acceptable rates in ice. However, frame-mounted units are required for hoisting and lowering when holes have to be drilled to considerable depths. The higher power that is usually available in a frame-mounted unit does not permit any significant increase in penetration rate over hand-held units, since cutting clearance sets a limit (an inept operator can twist off the auger stem if a highly powered unit is over-driven so that cuttings are jammed).

The U.S. Navy used a trailer-mounted drilling unit (approximately 5 tons) for experimental drilling in sea ice. Maximum penetration rate was 8 ft/min (41 mm/sec) with a 4.75 in. (0.12 m) diameter tricone roller bit, and 1 ft/min (5 mm/sec) with a 14 in. (0.36 m) O.D. (12 in. or 0.3 m I.D.) coring bit (Hoffman and Moser, 1967). Tests were also made with a 10 in. (0.25 m) diameter auger, which penetrated at 6 ft/min (30 mm/sec) (Beard and Hoffman, 1967).

For deep drilling in Greenland and Antarctica, USA CRREL has used an electromechanical coring drill. The drill bit had a maximum outside diameter of 6.13 in. (156 mm) and minimum inside diameter of 4.50 in. (114 mm). Penetration rates have been in the range of 0.12 to 0.66 ft/min (0.61 to 3.4 mm/sec) (Ueda and Garfield, 1968, 1969a, 1970).

A lightweight (500 lb or 230 kg) powered ice-coring auger developed by the former Arctic Construction and Frost Effects Laboratory (ACFEL) penetrated at 0.67 to 1.0 ft/min (3.4 to 5.1 mm/sec), taking 3 in. (76 mm) diameter core and making a 4.75 in. (121 mm) diameter hole (ACFEL, 1954).

From Mellor & Sellman
"Ice-Core Drilling" 1974

APPENDIX B

A COMPUTER SIMULATION PROGRAM FOR A RECIRCULATING HOT WATER JET ICE DRILL

"ICE PIK"

A COMPUTER SIMULATION PROGRAM

FOR A RECIRCULATING HOT WATER JET

ICE DRILL

GENERAL PROGRAM DESCRIPTION

The computer simulation model for a recirculating hot water jet ice drill utilizes standard heat transfer relationships and a very powerful analytical technique employing finite-difference approximations. A control volume is established around the drill probe and surrounding ice. Standard heat transfer relationships are used to perform the energy balance calculations. In the area where the jet stream impinges the ice, an empirical relationship derived by Yin-Chao Yen of the U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, is used in estimating the local heat transfer coefficient.

In applying the finite-difference approximation technique, the control volume of ice is divided into a finite number of elements. Five types of elements are established, each type defined by the mechanism of heat transfer occuring within that element. For each type element, heat transfer equations are written in terms of finite-differences. These equations are then solved using a digital computer.

The printout from the computer illustrates the progression of the drill probe through the ice and the resulting temperature changes within the ice elements and melt water.

PROGRAM SEQUENCE FROM INITIALIZATION THROUGH ONE ITERATION

I. Initialization:

1. Initialize all input parameters
2. Read in ice properties @ 32°F
3. Store a table of water properties from 32°F - 250°F
4. Define heating probe boundary and ice-water interface
5. Initialize each element, according to its volume, with an amount of energy equivalent to its heat of fusion
6. Initialize ice and water temperatures
7. Calculate temperature increment for linear variation of ice temperature with depth

II. Iteration 1:

A. Calculate all input variables to the finite difference equations.

* 1. If the temperature of the water has changed by more than 2°F, find new water properties by using a parabolic interpolation scheme on the water table.

* 2. Use Yen's emperical formulation of Nusselt number to calculate an average heat transfer coefficient for the jet impingement area.

3. Select a time increment to meet all convergence criteria of the finite difference equations.

4. For each element row above the impingement area, find film coefficients according to an emperical formula for turbulent flow through a short duct and a variable annulus diameter.

5. Find the volume of water in hole.

B. Calculate new ice temperatures.

1. For each element, scan the surrounding elements to determine which element model fits.

2. Find new temperatures of all ice elements.

C. Energy Balance.

1. For each element, calculate the amount of energy required to increase its temperature to the new valve.

a. If the new temperature is greater than 32°F, set it equal to 32°F and <u>reduce</u> the element's heat of fusion/solidification by an equivalent amount of energy.

b. Once an element's heat of fusion is reduced to zero, melt it and set its temperature to the bulk temperature of the water.

* 2. Calculate the total amount of energy flowing outward through a control volume drawn at the ice-water interface and extending upward to the top of the heating probe.

a. Sum over the entire element matrix of ice the following energy increments.

1. Internal energy increases
2. Heat of fusion reductions
3. Melted element increases to bulk water temperature

3. Subtract Energy Outflow from Probe input

D. Lower the Probe.

1. Scan the entire probe to insure clearance
2. Lower the probe an appropriate amount

a. Increment time and depth
b. Initialize new elements with a linearily varying temperature and their heat of fusion

* E. Calculate new bulk water temperature.

1. Using the results of the energy balance and assuming the melt water can be modeled as a well-stirred tank, calculate the new average temperature of the water.

F. Print out temperature profile and appropriate output parameters at selected time intervals.

---

* These calculations are either entirely new or significantly modified since presentation to the ADOM team, July 1978.

DERIVATION OF FINITE DIFFERENCE EQUATIONS - Refer to Figure 1

From the energy balance, the summation of all energy into a node equals the change in its internal energy. Table 1 defines the terms used in this derivation.

I. Element type 1. Conduction through all sides.

$$k2\pi R\frac{\Delta x}{\Delta y}(T_{I-1,J} - T_{I,J}) + k2\pi R\frac{\Delta x}{\Delta y}(T_{I+1,J} - T_{I,J}) +$$

$$k2\pi\left(R+\frac{\Delta x}{2}\right)\frac{\Delta y}{\Delta x}(T_{I,J-1} - T_{I,J}) + k2\pi\left(R-\frac{\Delta x}{2}\right)\frac{\Delta y}{\Delta x}(T_{I,J+1} - T_{I,J})$$

$$= \rho 2\pi R\frac{\Delta x\Delta y}{\Delta\theta} C_p (T^{n+1}_{I,J} - T^{n}_{I,J}) \quad (1)$$

Canceling like terms, dividing through by k and letting

$$\Delta x = \Delta y, \quad (2)$$

then define the following:

$$C = \frac{\Delta x^2}{\alpha\Delta\theta} \quad (3)$$

$$\text{where } \alpha = \frac{k}{\rho c_p}$$

$$C_3 = \frac{\Delta x}{2R} \quad (4)$$

$$C_2 = 1 - C_3 \quad (5)$$

$$C_1 = 1 + C_3\ . \quad (6)$$

Rewriting equation 1 with the above definitions yields:

$$T_{I-1,J} + T_{I+1,J} + C_1 \, T_{I,J-1} + C_2 \, T_{I,J+1} +$$

$$(C-2+C_1+C_2) \, T_{I,J} = C \, (T_{I,J}^{n+1}). \tag{7}$$

Note that:

$$C-2+C_1+C_2 = C-4, \tag{8}$$

therefore equation 7 becomes:

$$T_{I,J}^{n+1} = \frac{1}{C} (T_{I-1,J} + T_{I+1,J} + C_1 \, T_{I,J-1} + C_2 \, T_{I,J+1}) +$$

$$(1- \frac{4}{C}) \, T_{I,J}. \tag{9}$$

To satisfy convergence criteria:

$$1- \frac{4}{C} \geq 0$$

$$\text{or } C \geq 4. \tag{10}$$

From equation 3:

$$C= \frac{\Delta x^2}{\alpha \Delta\theta} \geq 4. \tag{11}$$

From equation 11 it can be seen that the time increment $\Delta\theta$ must be chosen less than or equal to:

$$\frac{\Delta x^2}{4\alpha} . \tag{12}$$

II. Element type 2. Convection through side (I,J+1).

$$k2\pi R \frac{\Delta x}{\Delta y} (T_{I-1,J} - T_{I,J}) + k2\pi R \frac{\Delta x}{\Delta y} (T_{I+1,J} - T_{I,J}) +$$

$$k2\pi \frac{\Delta y}{\Delta x} (R+ \frac{\Delta x}{2}) \quad (T_{I,J-1} - T_{I,J}) +$$

$$\frac{h2\pi}{k} (R- \frac{\Delta x}{2}) \Delta y \, (T_{I,J+1} - T_{I,J}) =$$

$$\alpha 2\pi R \frac{\Delta x \Delta y}{k \Delta\theta} C_p \, (T_{I,J}^{n+1} - T_{I,J}). \tag{13}$$

Canceling like terms and using the previous definitions for C, C_1, C_2, and C_3 as before, equation 13 can be written as:

$$T^{n+1}_{I,J} = \frac{1}{C}\left(T_{I-1,J} + T_{I+1,J} + C_1\, T_{I,J-1} + \frac{h}{k} C_2 \Delta x\, T_{I,J+1}\right) +$$

$$\left(1-\frac{1}{C}\left(3 + C_3 + \frac{hC_2\Delta x}{k}\right)\right) T_{I,J} \,. \tag{14}$$

To satisfy convergence criteria:

$$1-\frac{1}{C}\left(3+C_3 + \frac{hC_2\Delta x}{k}\right) \geq 0. \tag{15}$$

With Δx small with respect to R,

$C_3 \cong 0$

and equation 16 reduces to:

$$C= \frac{\Delta x^2}{\alpha\Delta\theta} \geq 3 + \frac{h\Delta x}{k} \tag{16}$$

and

$$\Delta\theta \leq \frac{\Delta x^2}{\alpha\left(3+ \frac{h\Delta x}{k}\right)} \,. \tag{17}$$

Equation 18 illustrates the effect that the heat transfer coefficient has on the time increment $\Delta\theta$. For a large heat transfer coefficient, $\Delta\theta$, the time increment for each iteration, approaches a very small number.

III. Element type 3. Convection through top (I-1,J).

$$h2\pi R\frac{\Delta x}{R}\left(T_{I-1,} - T_{I,J}\right) + k2\pi R\frac{\Delta x}{\Delta y}\left(T_{I+1,} - T_{I,J}\right) +$$

$$k2\pi\frac{\Delta y}{\Delta x}\left(R+\frac{\Delta x}{2}\right)\left(T_{I,J-1} - T_{I,J}\right) +$$

$$k2\pi\frac{\Delta y}{\Delta x}\left(R-\frac{\Delta x}{2}\right)\left(T_{I,J+1} - T_{I,J}\right) =$$

$$\rho 2\pi R\,\frac{\Delta x\Delta y}{k\Delta\theta}\,C_p\left(T^{n+1}_{I,J} - T_{I,J}\right) \tag{18}$$

Rearranging and rewriting equation 19 yields:

$$T^{n+1}_{I,J} = \frac{1}{C}\left(\frac{h\Delta x}{k}T_{I-1,J} + T_{I+1,J} + C_1 T_{I,J-1} + C_2 T_{I,J+1}\right) +$$

$$\left(1-\frac{1}{C}\left(\frac{h\Delta x}{k} + 3\right)\right)T_{I,J}\ . \tag{19}$$

To satisfy convergence criteria:

$$1 - \frac{1}{C}\left(\frac{h\Delta x}{k} + 3\right) \geq 0 \tag{20}$$

from which:

$$\Delta\theta \leq \frac{\Delta x^2}{\alpha\left(\frac{h\Delta x}{k} + 3\right)} \tag{21}$$

IV. Element type 4. Convection through top (I-1,J) and side (I,J+1).

$$h2\pi R\Delta x\left(T_{I-1,J} - T_{I,J}\right) + k2\pi R\,\frac{\Delta x}{\Delta y}\left(T_{I+1,J} - T_{I,J}\right) +$$

$$k2\pi\,\frac{\Delta y}{\Delta x}\left(R + \frac{\Delta x}{2}\right)\left(T_{I,J-1} - T_{I,J}\right) +$$

$$h2\pi\left(R - \frac{\Delta x}{2}\right)\Delta y\left(T_{I,J+1} - T_{I,J}\right) =$$

$$\rho 2\pi R\,\frac{\Delta x\Delta y}{\Delta\theta}\,C_p\left(T^{n+1}_{I,J} - T_{I,J}\right). \tag{22}$$

Rearranging and rewriting equation 23 yields:

$$T^{n+1}_{I,J} = \frac{1}{C}\left(\frac{h\Delta x}{k}\left(T_{I-1,J} + C_2\, T_{I,J+1}\right) + T_{I+1,J} + C_1\, T_{I,J-1}\right) +$$

$$\left(1 - \frac{1}{C}\left(\frac{h\Delta x}{k}\,(1+C_2) + 2 + C_3\right)\right) T_{I,J} \qquad (23)$$

To satisfy convergence criteria:

$$1 - \frac{1}{C}\left(\frac{h\Delta x}{k}\,(1+C_2) + 2 + C_3\right) \geq 0 \quad .$$

from which ($C_3 \approx 0$):

$$\Delta\theta \leq \frac{\Delta x^2}{2\alpha\left(\frac{h\Delta x}{k} + 1\right)} \quad . \qquad (24)$$

The time increment given by equation 25 is the most restrictive criteria. In the program, this inequality is checked for each iteration.

V. Element type 5. Convection through bottom (I+1,J) and side (I,J+1).

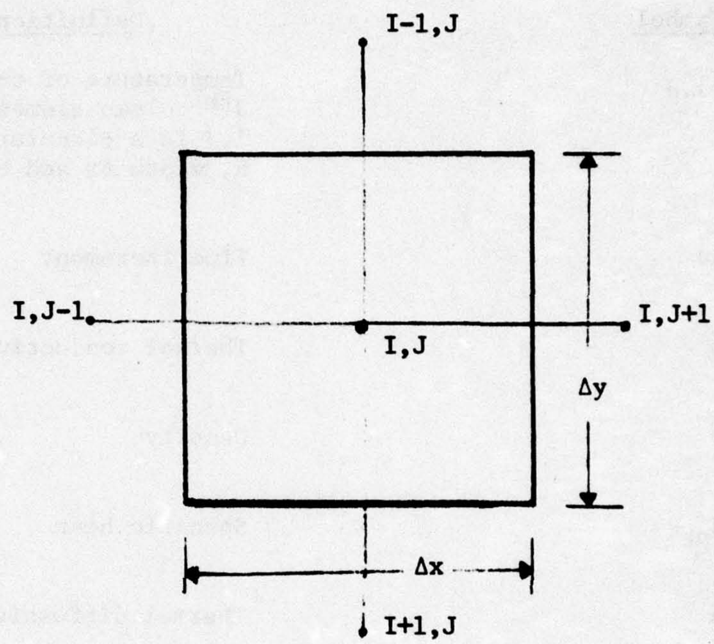
This derivation is identical to element type 4 with $T_{I+1,J}$ substituted for $T_{I-1,J}$ and vice versa, therefore:

$$T^{n+1}_{I,J} = \frac{1}{C}\left(\frac{h\Delta x}{k}\left(T_{I+1,J} + C_2\, T_{I,J+1}\right) + T_{I-1,J} + C_1\, T_{I,J+1}\right) +$$

$$\left(1 - \frac{1}{C}\left(\frac{h\Delta x}{k}\,(1+C_2) + 2 + C_3\right)\right) T_{I,J} \quad . \qquad (25)$$

Convergence criteria is the same as the criteria for element type 4.

Finite Difference Element Model



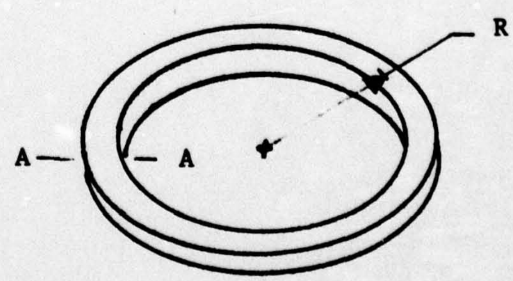
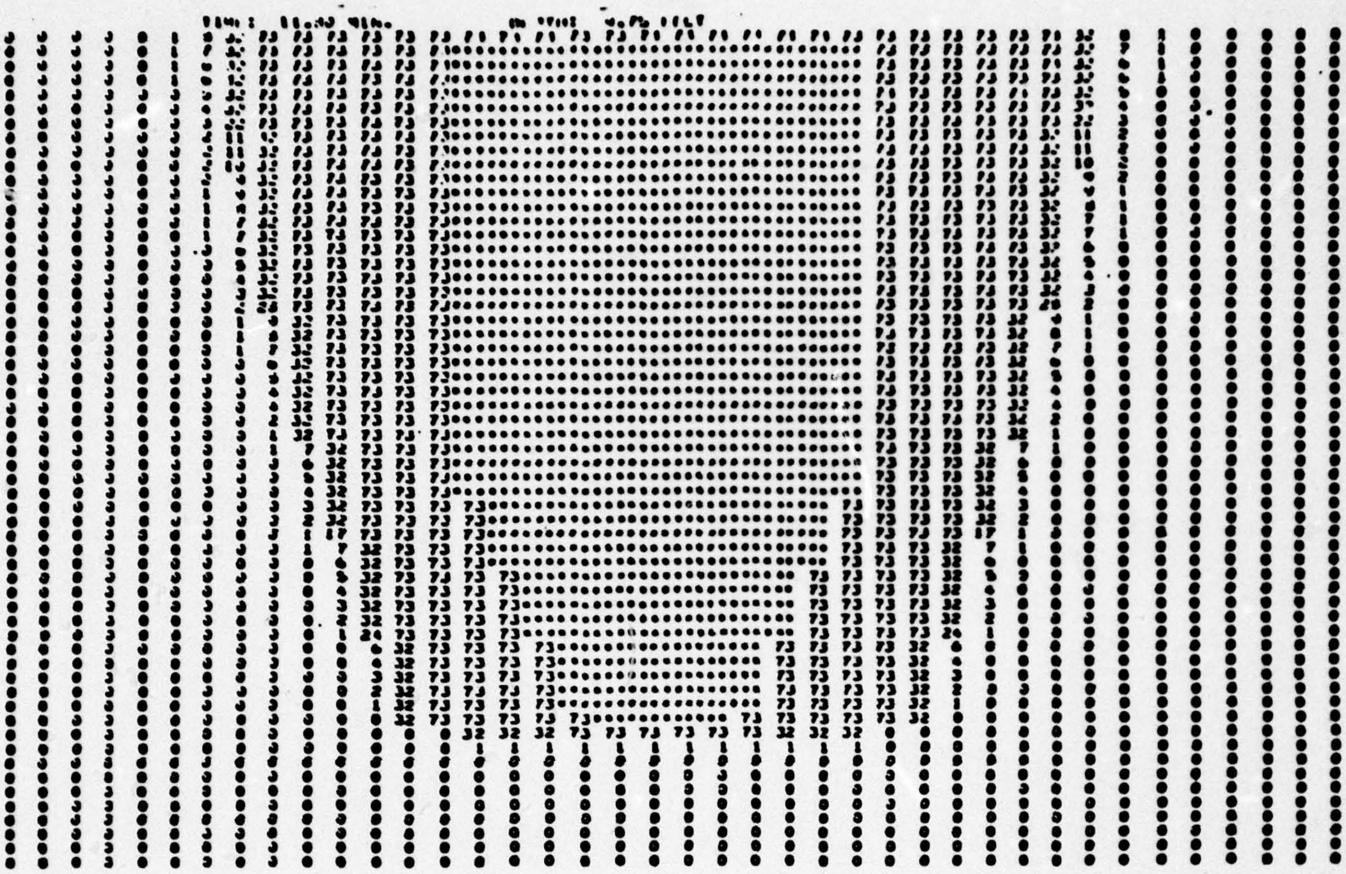


FIGURE 1

TABLE 1

Symbol	Definition
$T_{I,J}$	Temperature of the I^{th} row and J^{th} column element. Element I,J is a circular ring of radius R, width Δx and heighth Δy.
$\Delta\theta$	Time increment
k	Thermal conductivity
ρ	Density
C_p	Specific heat
α	Thermal diffussivity $\alpha = \frac{k}{\rho C_p}$

SAMPLE OUTPUT FROM COMPUTER SIMULATION PROGRAM



```
TIME:  12.01 MINUTES      DEPTH:  9.92 FEET

    DIMENSIONS OF HEATING PROBE:

        OVERALL:
            DIAMETER - 3.00 INCHES
            LENGTH - 12.00 INCHES

        NOZZLE:
            DIAMETER - 1.00 INCHES
            LENGTH -  5.00 INCHES

    INTERPOLATED PROPERTIES OF WATER AT A BULK TEMPERATURE OF  73 DEGREES F :

        DENSITY - 62.267 LBM/CU FT
        VISCOSITY - .6302E-03 LBM/FT-SEC
        CONDUCTIVITY - 0.3450 BTU/HR-FT-F.
        PRANDTL -  6.531

    INPUT PARAMETERS:

        POWER - .1228E+06 BTU/HR
        NOZZLE EXIT VELOCITY - 25.00 FT/SEC
        VOLUMETRIC FLOW RATE -  61.20 GAL/MIN

    JET PARAMETERS (BELOW ELEMENT NO. # 50 ):

        NONDIMENSIONAL CHARACTERISTICS:
            REYNOLDS - .2059E+06
            NUSSELT - .2634E+04
        AVERAGE HEAT TRANSFER COEFFICIENT:
            H - .1103E+05 BTU/HR-SQ FT-F.

    ANNULUS PARAMETERS (AT ELEMENT NO. # 1):

        VELOCITY -  2.78 FT/SEC
        NONDIMENSIONAL CHARACTERISTICS:
            REYNOLDS - .6H62E+05
            NUSSELT - .4352E+01
        HEAT TRANSFER COEFFICIENT:
            H - .6975E+03 BTU/HR-SQ FT-F.

    DIAMETER AND VOLUME OF HOLE:

        DIAMETER - 4.00 INCHES
        VOLUME - 3.13HE CU FT
```

APPENDIX C

EXPERIMENTAL DESIGN FOR A RECIRCULATING HOT WATER JET IN SUPPORT OF A COMPUTER SIMULATION PROGRAM

EXPERIMENTAL DESIGN

FOR A

RECIRCULATING HOT WATER JET

IN SUPPORT OF A

COMPUTER SIMULATION PROGRAM

TO BE PERFORMED AT THE

USA COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NH

Prepared by

MARINE SYSTEMS ENGINEERING LABORATORY
University of New Hampshire, Durham, NH

November 1978

TABLE OF CONTENTS

1.0 INTRODUCTION AND PURPOSE OF EXPERIMENT

The University of New Hampshire, through its Marine Systems Engineering Laboratory (MSEL), is involved with the Arctic aspect of the Air Deployed Oceanographic Mooring (ADOM) program sponsored by the Office of Naval Research. The purpose of the ADOM program is to develop the technology necessary for cost effective and successful air deployment and operation of unmanned oceanographic instrumentation systems. Within this program, two systems are being developed; one for deployment in the open oceans and one for deployment in the ice covered polar oceans. Of interest to MSEL is the ice covered ocean system.

Deploying oceanographic instrumentation in ice covered oceans requires a system that is launched from an aircraft, penetrates up to approximately 50 feet of ice and then deploys the instrumentation. Only small diameter holes are considered, ie. less than 6 inches. After an exhaustive analysis of ice penetrating techniques, MSEL has chosen for further study, one concept that shows substantial promise as an efficient and workable technique. This conceptual technique for penetrating the ice consists of a recirculating hot water jet probe. Water, heated internally in the probe, is pumped out the end of the probe at high velocity through a nozzle, and strikes the ice below. As melt water develops, it is continuously recirculated into the probe and pumped out as a hot jet stream. The jet stream significantly increases the transfer of heat energy from the water to the ice than could be achieved through conduction and/or natural convection. Recirculating the melt water reduces the

energy lost to the surrounding ice. Figure 1 is an illustration of the drill probe.

To further study the hot water jet concept, a thermodynamic analysis of the probe's operation was undertaken, and a computer simulation program developed. This computer program, named "ICE PIK", models the drill probe as it proceeds through the ice after an initial start up phase. Appendix A contains an example of the computer printout produced from "ICE PIK".

In developing the computer program, certain assumptions were made concerning the heat transfer relationships between the jet stream and the ice. The purpose of this experiment will be to gain insight into these heat transfer relationships, thereby providing the data necessary to "calibrate" the computer model and more accurately predict the drill's performance under varying conditions.

2.0 DESCRIPTION OF EXPERIMENT

2.1 EXPERIMENTAL APPARATUS

In is anticipated that the basic experimental apparatus will be similar to that used by CRREL in the study of an annular flow ice-water heat sink. The ice will be contained in a large tank, 6 feet in diameter by 10 feet in height. Figure 2 illustrates the apparatus. The ice drill will be supported over the ice tank in a manner that will keep it vertical during the test, but allowing it to move vertically downward as the drilling process progresses.

A measuring scale placed alongside the drilling probe, but fixed relative to the tank will allow measurement of the hole depth during the test.

Temperature probes will monitor the drill inlet and outlet water temperatures. It is anticipated that additional temperature probes will be placed within the tank such that ice temperatures can be determined prior to, and after, the test runs.

The 24 to 30 KW immersion heater will be used to simulate the drill probe's interior heating rods. The electric motor and pump assembly will be used to circulate the water used by the drill probe simulating the probe's internal pump. Figure 3 illustrates the anticipated flow rates for the experiment.

A drain hole will have to be provided at the top of the tank near the ice level to allow for drainage of the initial burst of hot water. A description of the proposed test procedure follows.

2.2 TEST PROCEDURE

The experiment will consist of two phases which are in decreasing order or priority. Phase I - A study of the overall drill probe design as presently conceived. Phase II - A study of the nozzle isolated

from the effects of the probe body. Phase I will allow study of the entire drill probe assembly's performance and determination of overall heat transfer coefficients for various nozzle sizes and flow rates. Figure 4 illustrates the probe's anticipated configuration. Phase II will allow further study of only the nozzle portion of the drill without the effects of annular flow as modeled in Phase I. It is anticipated that the majority of melting, and therefore the higher heat transfer coefficient, is due to the high velocity hot water jet rather than the annular flow of hot water around the body of the probe. Study of the nozzle will allow a means of determining this higher heat transfer coefficient and give us further insight into the drilling process. Figure 5 illustrates the nozzle assembly.

The following general test procedure is common to both Phase I and Phase II.

The tank will be initially filled with fresh water and allowed to freeze, then stand for some period of time to equilibriate, expected to be 3 days. Before each test, the probe's intake line will be primed and the ice temperature recorded. Immediately prior to the test run, the strip chart recorders are turned on and adjusted for proper operation. To initiate drilling, a water source other than melt water, will be used. This second source of water will simulate start up water carried onboard the ADOM vehicle, one of several start up concepts being studied. As soon as the drilling probe has progressed far enough for adequate melt water production, the melt water recirculation process will begin and continue until the test run is terminated. Transition from using the start up water to recirculating melt water will be done manually by opening and closing appropriate valves (valves A and B in Figure 2).

Termination of the test run will occur before tank boundries can influence the test data. Figure 6 illustrates the various parameters to be measured before, during, and/or after each test run.

After each run, the melt water will be allowed to refreeze and come to an equilibrium temperature before the next run. Approximately 3 days are expected to be required to refreeze the melt water and allow the ice to reach an equilibrium temperature. If possible, it would be highly desireable to perform more than one test run per refreeze cycle. Perhaps 3 test runs could be performed per refreeze cycle without adversely influencing the data.

2.3 TESTING SCHEDULE

Following is an estimated test schedule for Phases I and II. Test schedule A reflects one test run per refreeze cycle, test schedule B reflects 3 test runs per refreeze cycle. One replicate series of tests is anticipated. The amount of time available for the experiment is set at one month.

2.3.1 TEST SCHEDULE A

Limited to one test run per refreeze cycle, approximately 8 test runs can be completed in a one month period based on two refreeze cycles per week. With these restrictions, only Phase I testing will be performed and with a reduction in number of flow rates from 3 to 2. Figure 7 shows the estimated test schedule.

2.3.2 TEST SCHEDULE B

Based on 3 test runs per refreeze cycle and 2 refreeze cycles per week, 24 test runs can be accomodated in a one month period. These 24 runs would allow completion of Phase I and II in their entirety. Figure 8 shows the estimated test schedule.

3.0 DATA ANALYSIS

The data will be analyzed to derive an approximation of the heat transfer coefficient for the overall drilling process in Phase I and for the nozzle in Phase II provided Phase II is performed. Appendix C contains the derivation of an expression for the heat transfer coefficient. Heat transfer coefficients for various flow rates and nozzle sizes will be plotted. Relationships of Nusselt number, Reynolds number (both based on nozzle diameter) and Prandtl number will be derived from the recorded data and the results will be plotted. The overall performance of the recirculating hot water jet as an ice drilling mechanism will be evaluated.

4.0 REFERENCES

1. Stubstad, John M. and Quinn, William F., "Experimental Scaling Study of an Annular Flow Ice-Water Heat Sink," U.S.A. CRREL Report 77-15.

DRILL PROBE

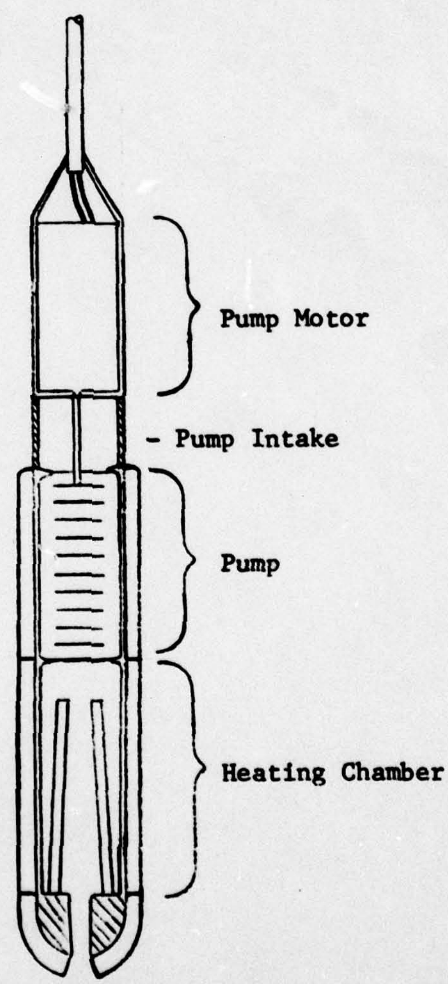
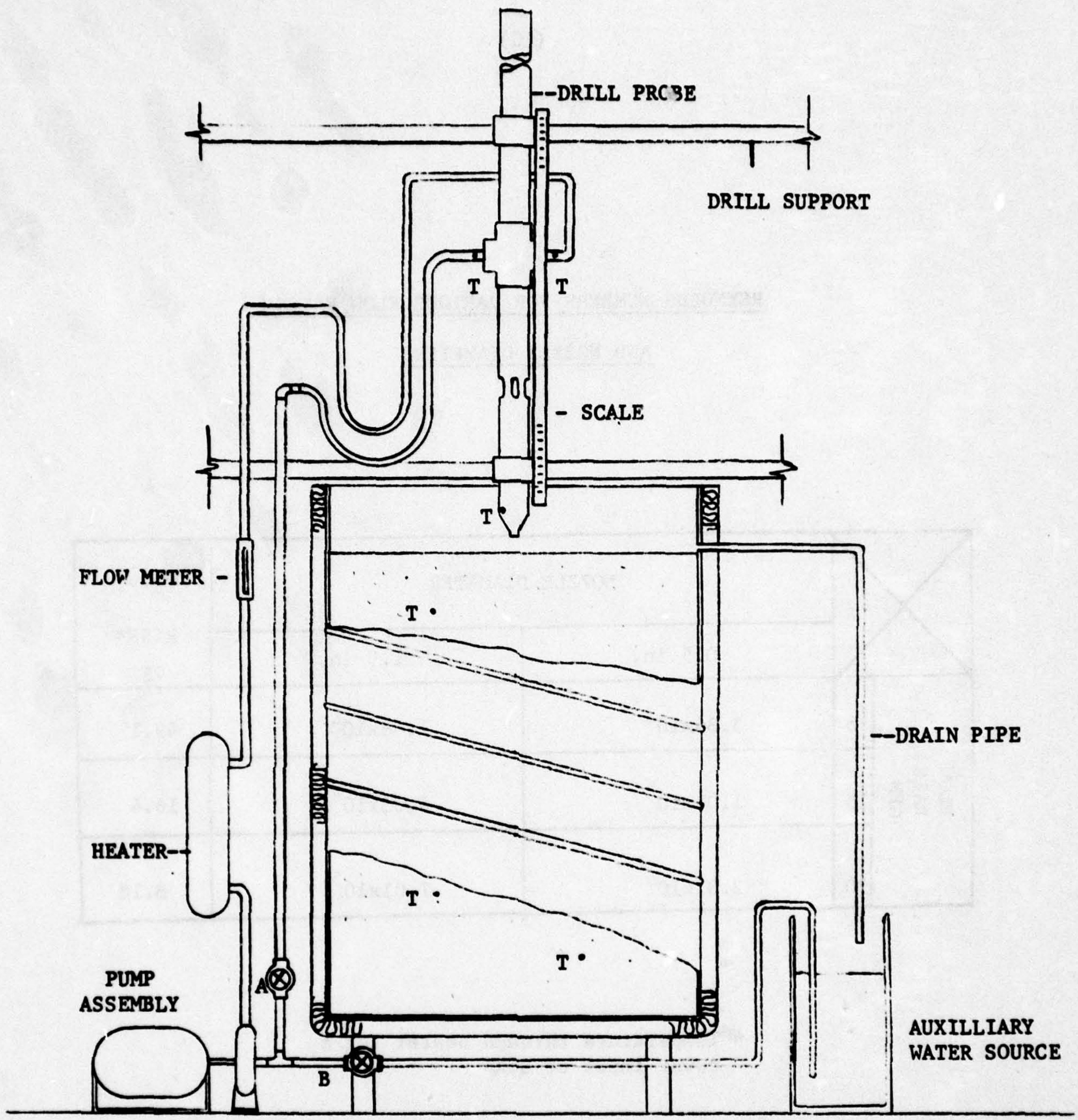


FIGURE 1



(T) Indicates temperature sensor

<u>EXPERIMENTAL APPARATUS</u>

FIGURE 2

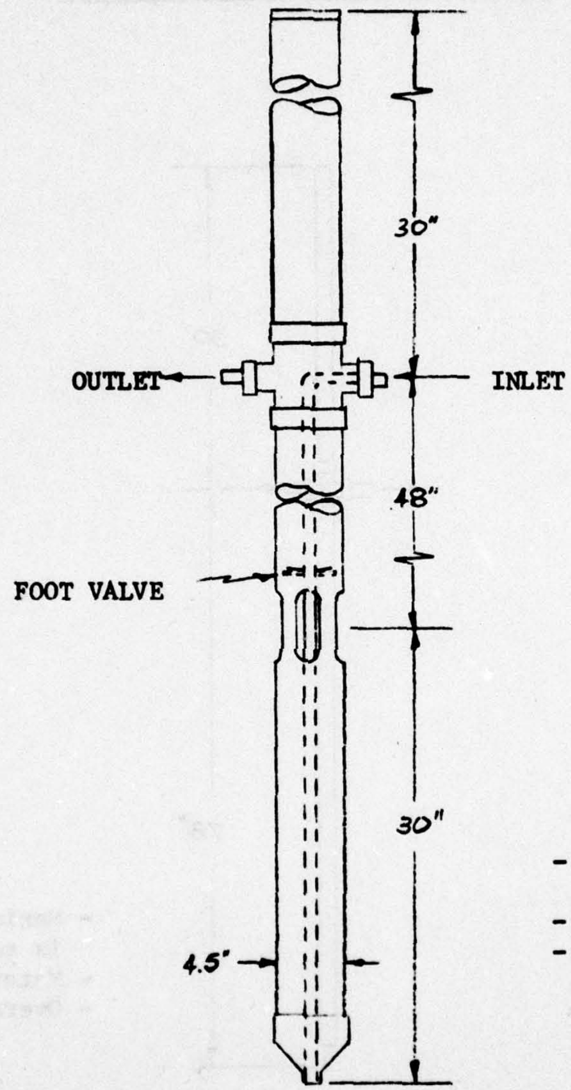
REYNOLDS NUMBERS FOR VARIOUS FLOW RATES AND NOZZLE DIAMETERS

FLOW RATE GPM	NOZZLE DIAMETER 0.5 in.	NOZZLE DIAMETER 1.0 in.	TEMP. RISE* °F
5	3.36×10^4	1.68×10^4	49.1
15	1.01×10^5	5.03×10^4	16.4
30	2.01×10^5	1.01×10^5	8.18

* Temperature through heater for a power input of 36KW

FIGURE 3

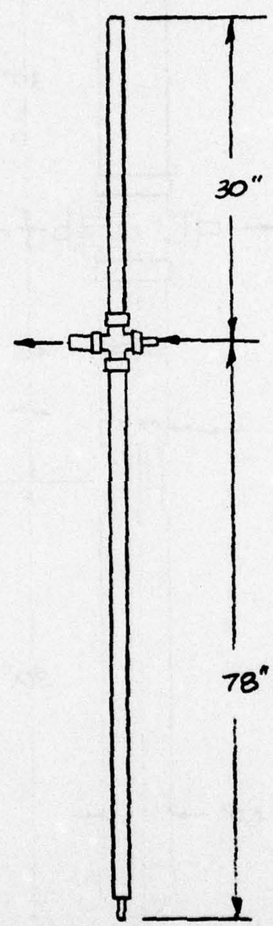
EXPERIMENTAL PROBE CONFIGURATION



- Maximum drilling depth is set at 6 feet.
- Materials PVC.
- 108" overall length.

Figure 4

EXPERIMENTAL NOZZLE CONFIGURATION



- Maximum drilling depth is set at 6 feet.
- Material is PVC
- Overall length is 108".

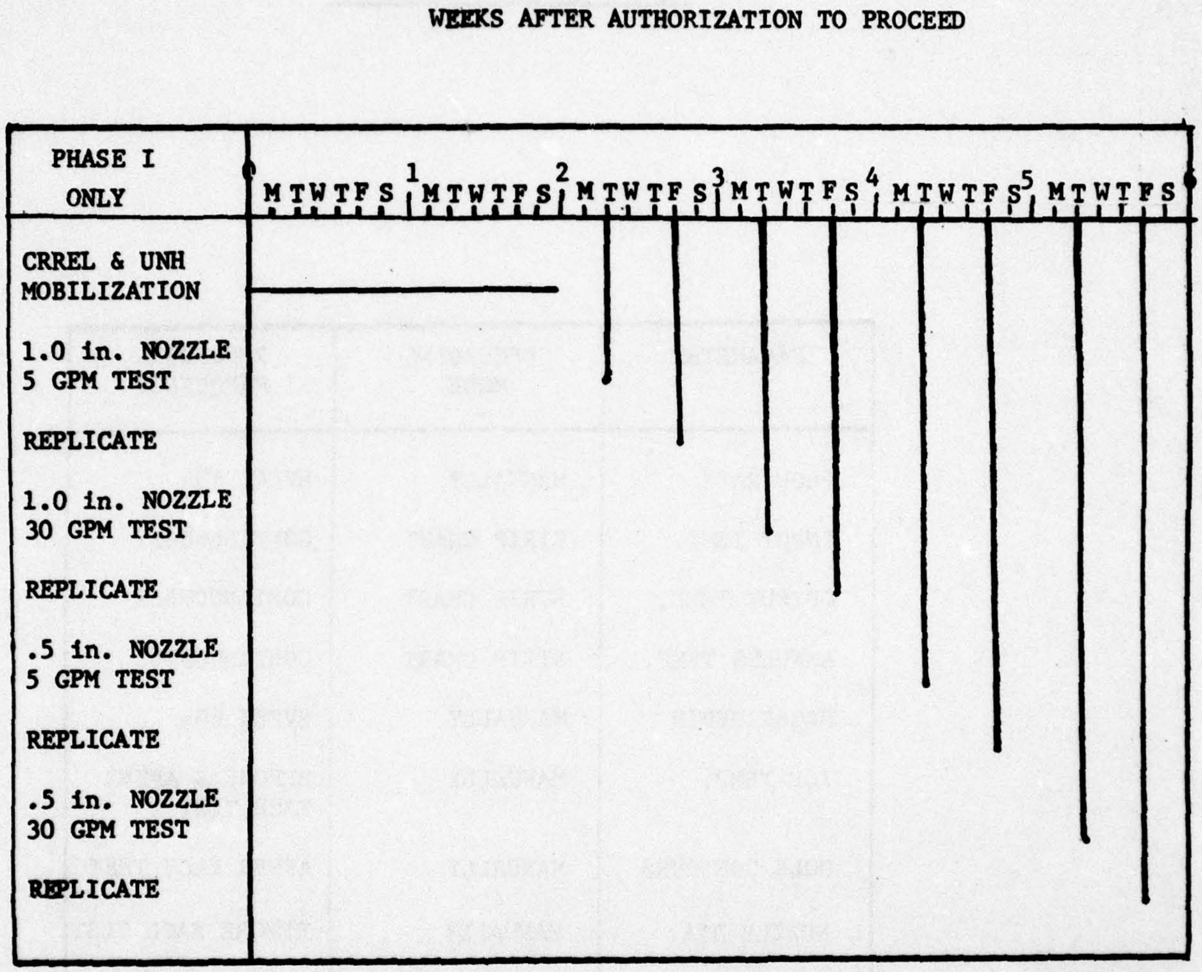
Figure 5

MEASURED TEST PARAMETERS

PARAMETER	RECORDING MODE	RECORDING FREQUENCY
FLOW RATE	MANUALLY	EVERY 60s
INPUT TEMP.	STRIP CHART	CONTINUOUSLY
OUTPUT TEMP.	STRIP CHART	CONTINUOUSLY
ANNULUS TEMP.	STRIP CHART	CONTINUOUSLY
PROBE DEPTH	MANUALLY	EVERY 60s
ICE TEMP.	MANUALLY	BEFORE & AFTER EACH TEST
HOLE CONTOURS	MANUALLY	AFTER EACH TEST
NOZZLE DIA.	MANUALLY	BEFORE EACH TEST

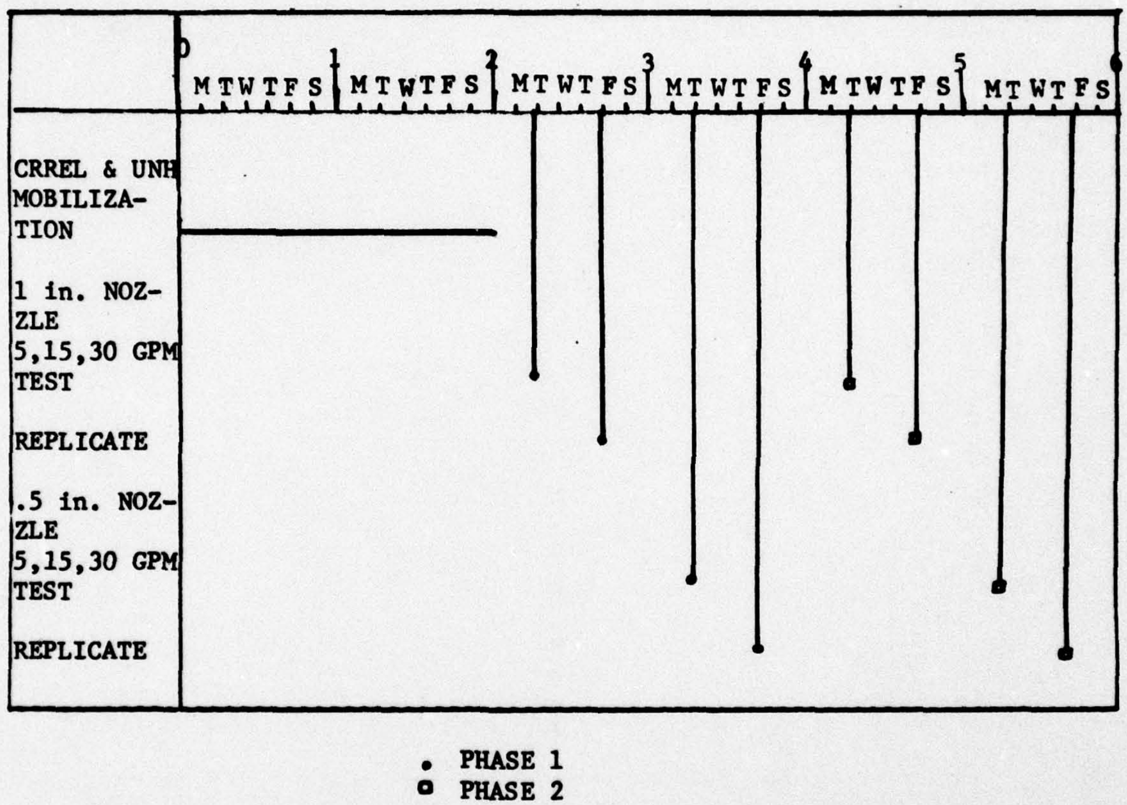
Time base will be determined from strip chart recorder speed and a watch.

FIGURE 6



TEST SCHEDULE A

FIGURE 7

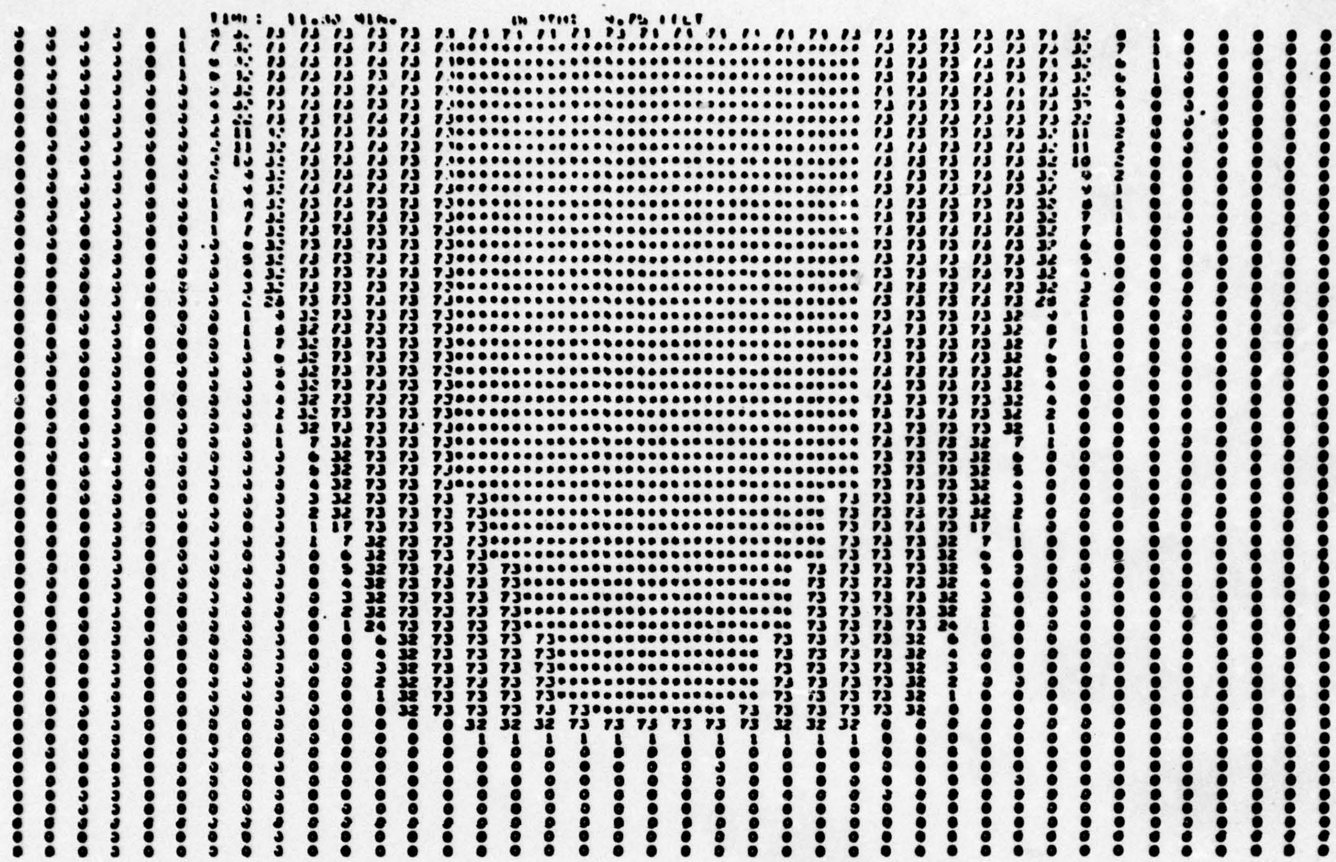


TEST SCHEDULE B

FIGURE 8

APPENDIX A

SAMPLE OUTPUT FROM COMPUTER SIMULATION PROGRAM



```
TIME:  12.01 MINUTES      DEPTH:  9.92 FEET

     DIMENSIONS OF HEATING PROBE:

          OVERALL:
             DIAMETER - 3.00 INCHES
             LENGTH - 12.00 INCHES

          NOZZLE:
             DIAMETER - 1.00 INCHES
             LENGTH -  5.00 INCHES

     INTERPOLATED PROPERTIES OF WATER AT A BULK TEMPERATURE OF   73 DEGREES F :

          DENSITY - 62.267 LBM/CU FT
          VISCOSITY - .6302E-03 LBM/FT-SEC
          CONDUCTIVITY - 0.3490 BTU/HR-FT-F.
          PRANDTL -  6.501

     INPUT PARAMETERS:

          POWER - .1228E+06 BTU/HR
          NOZZLE EXIT VELOCITY - 25.00 FT/SEC
          VOLUMETRIC FLOW RATE -  61.20 GAL/MIN

     JET PARAMETERS (BELOW ELEMENT NO. # 50 ):

          NONDIMENSIONAL CHARACTERISTICS:
             REYNOLDS - .2056E+06
             NUSSELT - .2634E+04
          AVERAGE HEAT TRANSFER COEFFICIENT:
             H - .1103E+05 BTU/HR-SQ FT-F.

     ANNULUS PARAMETERS (AT ELEMENT ROW # 1):

          VELOCITY -  2.78 FT/SEC
          NONDIMENSIONAL CHARACTERISTICS:
             REYNOLDS - [illegible]
             NUSSELT - .6352E+0[illegible]
          HEAT TRANSFER COEFFICIENT:
             H - .6075E+03 BTU/HR-SQ FT-F.

     DIAMETER AND VOLUME OF HOLE:

          DIAMETER - 6.00 INCHES
          VOLUME - 3.1346 CU FT
```

APPENDIX B

Symbol	Definition	Units
A	Area for heat transfer	ft^2
h	Heat transfer coefficient	$BTU/m\text{-}ft^{2\,o}F$
H	Depth of hole	ft
L	Latent heat of fusion	BTU/lbm
M_i	Mass of ice melted	lbm
Q_m	Heat	BTU
R	Hole radius	ft
t	Time	hr
ΔT	Temperature difference	^oF
$\bar{T}_B$	Average bulk water temperature	^oF
$\bar{T}_{IN}$	Average probe inlet temperature	^oF
$\bar{T}_{OUT}$	Average probe outlet temperature	^oF
V	Volume	ft^3
pi	Density of ice	lbm/ft^3
V_{i_l}	Volume of ice	ft^3

APPENDIX C*

HEAT TRANSFER COEFFICIENT

The rate of heat transfer between two surfaces is given by:

$$dQ_m = hA\ \Delta T\ dt \qquad (1)$$

Where ΔT is the temperature difference between the two surfaces. Considering the jet drill probe, ΔT represents the difference between the ice melting surface temperature and the bulk water temperature.

If the ice temperature is initially at 32^oF, then all the energy goes to melting the ice and is given by the following expression:

$$dQ_m = M_i\ L \qquad (2)$$

The mass of the ice melted is given by:

$$M_i = \rho_i \nabla_i$$

It is assumed that all melting occurs in a hemisphere around the nozzle (Figure AC-1).

From Figure AC-1:

$$\nabla_i = V_1 - V_2$$

$$\nabla_i = \tfrac{1}{2}(\tfrac{4}{3}\pi R^3) + \pi R^2\ dH - \tfrac{1}{2}(\tfrac{4}{3}\pi R^3)$$

$$\nabla_i = \pi R^2\ dH$$

Therefore:

$$M_i = \rho_i\ \pi R^2\ dH \qquad (3)$$

and substituting equation 3 into equation 2 yields:

$$dQ_m = \rho_i\ L\pi R^2\ dH \qquad (4)$$

The effective melting surface A is therefore given by:

$$A = \pi R^2$$

so that equation 4 becomes:

$$dQ_m = \rho_i\ LAdH \qquad (5)$$

Equating equations 1 and 5 and solving for h yields:

$$h = \frac{\rho_i L}{\Delta T}\ \frac{dH}{dt} \qquad (6)$$

---

* This work is based on a similar derivation contained in reference number 1.

In order to determine an approximation of the heat transfer coefficient, h, from experiment the following approximations and assumptions are made.

The average bulk water temperature can be approximated by:

$$\overline{T}_B = \tfrac{1}{2}(\overline{T}_{IN} + \overline{T}_{OUT})$$

Assuming the ice is initially at 32°F, the expression for ΔT becomes:

$$\Delta T = \overline{T}_B - 32$$

$$\text{or} \quad \Delta T = \tfrac{1}{2}(\overline{T}_{IN} + \overline{T}_{OUT}) - 32$$

The rate of change of holed depth with time can be approximated as follows:

$$\frac{dH}{dt} \approx \frac{\Delta H}{\Delta t}$$

Where ΔH is the change in hole depth in the time interval Δt.

With these assumptions and approximations, the heat transfer coefficient can be determined from parameters measured during the test. Equation 6 becomes:

$$h \approx \frac{\rho_i L}{\left[\tfrac{1}{2}(\overline{T}_{IN} + \overline{T}_{OUT}) - 32\right]} \frac{\Delta H}{\Delta t} \qquad (7)$$

APPROXIMATION OF ICE MELTING GEOMETRY

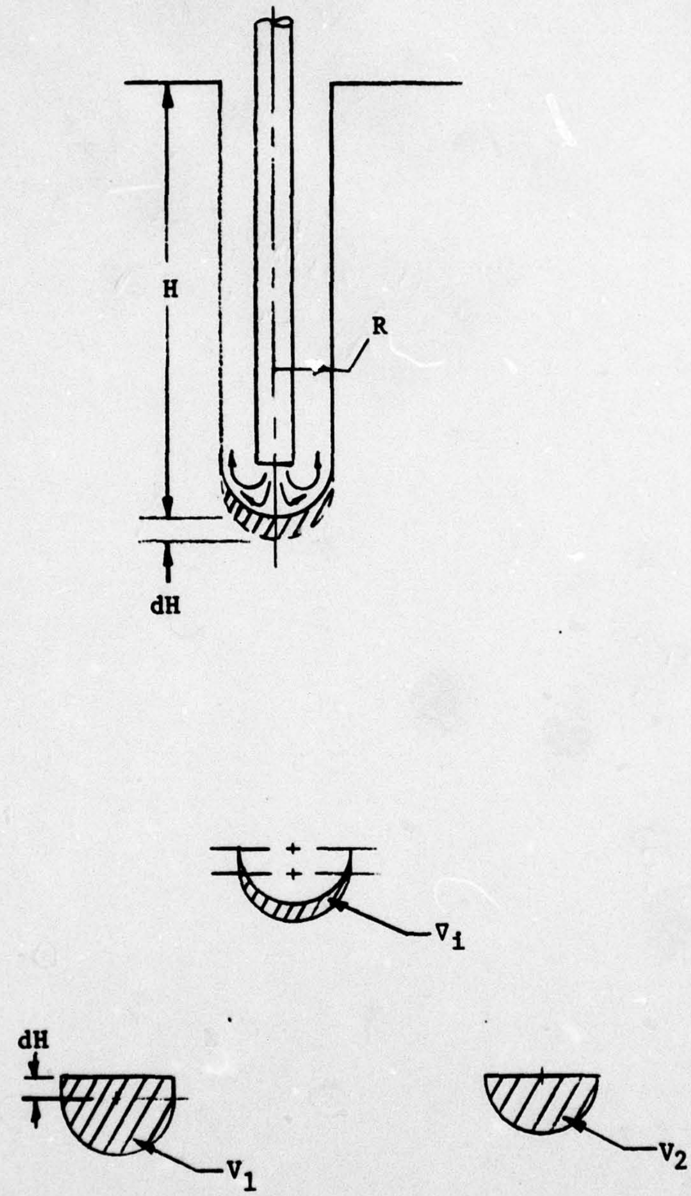


FIGURE AC-1

APPENDIX D

PROPOSED PARTICIPANTS RESPONSIBILITIES

UNH

1. Mobilize test probe and nozzle configurations
2. Supply strip chart recorders
3. Supply temperature sensors and scale for probes
4. Supervise and perform testing

CRREL

1. Mobilize test facility
2. Install temperature sensors in ice block
3. Maintain ice block after each test
4. Assist in performance of testing

APPENDIX D

TASK DESCRIPTIONS ESTABLISHED AT PROGRAM START

TASK DESCRIPTIONS ESTABLISHED AT PROGRAM START

PHASE I - CONCEPT DEFINITION PHASE

The concept definition phase of this proposed study will focus on two basic objectives:

1. Establishing a sound technical basis for penetrating the ice-covered oceans. The concepts and systems developed will be consistent with the ADOM concept as outlined in the ONR Progress Report of August 1977.
2. Contributing Arctic engineering concepts and technologies to the ADOM team.

A concept definition study is proposed consisting of the following elements:

1. Assessment of Arctic technologies and data bases
2. Examination of ice penetration system concepts
3. Analysis of system characteristics and trade off studies of ice penetration concepts
4. Development of a preferred design concept for ice penetration
5. Recommendations for a concept validation phase

These five elements are discussed below.

1. Assessment of Arctic Technologies and Data Bases

Many workers have considered the problems of ice drilling in polar regions; principal among these are the U. S. Army Cold Regions Research and Engineering Laboratory (CRREL), the Canadian Polar Shelf Study, and the extensive studies of the Russians and Japanese. The full extent of this technology will be gathered, assimilated and abstracted. Assumptions made earlier in the ADOM Program will be verified. A full assessment of applicable Arctic technologies and data bases will be

made and related to the ADOM Program.

2. <u>Examination of Ice Penetrator System Concepts</u>

Detailed examination will be made of the four drilling systems that are currently believed to show some potential for unmanned applications. These are:

A. Electro-thermal, whereby a battery driven resistive element heats the ice, lowering the instruments, while leaving the main system package on the ice surface.

B. Chemo-thermal drilling, where the energy source is a chemical, releasing heat on command or on contact with the ice.

C. Impact penetrometers, creating a hole through the impact of an air dropped element, with the remainder of the system probably landing by a tethered parachute to reduce deceleration forces.

D. Mechanical augers. Here unmanned adaptations of existing technology is contemplated.

In the Appendix, these concepts are briefly developed, and useful references in the literature are noted. Perceptions of scientists, familiar with the technologies, are also noted.

The potential for systems that avoid drilling by employing open water deployment in leads will also be examined. A reevaluation will be made of the available ice-thickness histogram and of ice characteristics as they relate to the needs of this project.

Alternative drilling systems will be sought out to broaden the list. The study will further review and recommend candidate aircraft for deployment in polar regions.

3. Analysis of System Characteristics and Trade-Off Studies of Ice Penetration Concepts

A detailed analysis will be made to establish specific characteristics of each system concept. These system parameters then will be compared to determine an optimum system concept.

System characteristics which will be included in the studies and tradeoff analysis are:

- energy requirements
- size
- weight
- applicability of available technology
- portability/ease of air deployment
- failure modes
- reliability and survivability
- Arctic environment compatibility
- cost
- prototype fabrication time
- compatibility with existing ADOM components

The outcome of this aspect of the study is conceived to be a thorough understanding of the current state of the art of ice penetration and related technologies and their potential to the ADOM Program.

4. Development of Design Concept for Ice Penetration

Having determined specific optimum parameters, a design concept will be developed. An initial system design will be made in sufficient detail to support a concept validation model and to permit reassessment of the time schedule as well as the development costs involved in the prototype system fabrication and testing.

5. Recommendation for a Concept Validation Phase

Phase I will terminate with a distribution of all background data to the ADOM Committee, a full technical presentation to the committee and a thorough analysis and review of the design. Due to time limita-

tions which exist in the ADOM schedule, the design concept which will be selected for fabrication of a prototype system must have the maximum probability of success. An effort will be made, throughout Phase I, to inform the ADOM Committee of pertinent design implications as they evolve. In this manner, it will be possible to recognize potential problem areas which might interfer with other components of the ADOM system. A recommendation for one design concept for ice penetration and for undertaking a validation study will be made by July 1, 1978. It is expected that the ADOM Committee will meet during July to consider this design concept and to establish, in consultation with ONR, the framework for the Phase II effort.

APPENDIX E

PROPOSED WORK PLAN OUTLINE FOR FISCAL YEAR 1979

PROPOSED WORK PLAN OUTLINE FOR FISCAL YEAR 1979

1. Complete CVM design for a manually operated ice drill system. The actual drill probe will be designed to be manually operated, ie. without its final automated control system, and will be dimensionally identical to the proposed drilling system for the ice ADOM based on knowledge at this time.

2. Fabricate the CVM ice drill system and perform in-house testing and checkout. A parallel effort will be focused on initial ADM design concepts with input from; array and processor configuration, hydrodynamic analysis of sensor and drill string, decelerator system and navigation system.

3. Perform a series of tests of the CVM at the U.S. Army Cold Regions Research and Engineering Laboratory in Hanover, NH simulating an Arctic environment.

4. Review the initial ADM design concepts with input from; CVM testing, stability studies, updated array and processor configuration, updated hydrodynamic analysis of sensor and drill string, updated decelerator system, updated navigation system, and updated shell shapes and weights.

5. Complete the ADM design for review by the ADOM project team. The ADM will be a complete automatically operated, self contained ice drilling system.